SPECIAL

INDIAN SCIENCE CONGRESS NUMBER

THE AGRICULTURAL JOURNAL OF INDIA

AGRICULTURAL RESEARCH INSTITUTE, PUSA

PUBLISHED FOR

THE IMPERIAL DEPARTMENT OF AGRICULTURE IN INDIA

BY

THACKER, SPINK & CO. CALCUTTA

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PREFACE.

THE Third Indian Science Congress held at Lucknow in February 1916, was a great improvement on the first and second meetings, and the expectations of the promoters as to the advantages of such meetings were on this occasion shown to be justified. The Indian departmental system of Government is apt to restrict correspondence between members of its numerous scientific departments and public and private institutions and to create a state of water-tight compartments. This is a serious drawback to the interests of scientific progress in a country where most of the scientific work is carried on under the auspices of Government. A Science Congress breaks down these barriers and brings together men of varied shades of opinion in every branch of scientific activity, and enables them to check and discuss problems in a manner for which the ordinary Government reports and publications offer no corresponding facilities. It also aids in the sifting of the good from the bad and gives the public, which is none too well informed on scientific matters, an opportunity of becoming acquainted with the doings of science. For these reasons the Indian Science Congress would seem to deserve every encouragement. It is hoped that it will continue to improve and become a powerful weapon for the aid and advancement of scientific progress in India.

One of the features of the last Congress was the creation of an Agricultural Section in which papers related to problems affecting the agricultural industry were read and discussed. Some of these are of considerable interest, and it is thought that to bring out a selection in the form of a Special Congress Number of the Agricultural Journal of India will be appreciated by the readers of the Journal. This explains the reasons for the present issue.

INDORE :
Dated the 5th May, 1916.

BERNARD COVENTRY.

With acknowledgments to the Asiatic Society of Bengal, under whose auspices the Indian Science Congress was held, for their kindness in allowing us to publish the papers contained in this number *in extenso.*

EDUCATION IN ITS RELATION TO AGRICULTURE.

BY

BERNARD COVENTRY, C.I.E.,

Agricultural Adviser to the Government of India and Director of the Pusa Agricultural Research Institute.

"I am no educator, no teacher; I have made no psychological study of young people from an educational point of view, nor of the different methods of teaching suited to different ages, no statistical investigation of the influence of particular curricula in training the mind or furnishing it with useful information. I have, in short, neither made contributions to the science of education nor practised the art ....I can speak only as a member of the general public—not as an expert................not that I regard the view of the general public as unimportant................ The general public must, as all will admit, decide what is to be spent on education or, more strictly, on schools and colleges and professional educators, out of both public and private income—it is for them to decide on its relation to other social and family needs. But the concern of the public with education is not merely financial and administrative. It is more intimate than that. For education is not a subject like physics or chemistry on which only an expert has a right to an independent view. There are, no doubt, aspects of it of which only the expert can properly judge, there are experiments in it which only the expert can advantageously try, and there are, of course, departments of it in which the opinion of the expert is indispensable. But without depreciating either the science and art of education, it is clear that when we take education in its widest sense it concerns everybody and almost everybody is bound to have views about it."

These words were spoken by no less a person than Mrs. Henry Sidgwick in her address as President of the Section on Educational Science at the recent meeting of the British Association at Manchester.

I feel like Mrs. Sidgwick that I am "no educator and no teacher" and that an apology or at least an explanation is required from me for troubling you to-day in a subject on which I am not an expert. But when we have it on such an authority as Mrs. Sidgwick that education "concerns everybody and almost everybody is bound to have views about it" I feel I have a measure of sanction for imposing my views upon you. I do not propose, however, to make full use of this sanction and tell you all I think about education, but I propose to restrict my remarks to education in its relation to agriculture and further with the exception of an introductory statement dealing with a few facts, I do not propose to say much on the education of youth, but of that of the adult. You will probably all admit that this is quite a novel and peculiar way of dealing with the question of education, but I trust you will find it none the less interesting and instructive. I should like to say before I go any further that I claim no credit for the ideas I shall place before you. They all come from America and, like everything that comes from that wonderful country, they are exceedingly "cute" and practical and in my opinion are eminently applicable to India.

The population of British India comprises over 255 million souls. Of this vast multitude 80 per cent. or over 200 millions, that is to say, 4 in every 5 are dependent on agriculture. Any educational system therefore which does not take into consideration the relationship it should bear to agriculture is likely to be at a disadvantage. It is on the importance of this aspect of the educational problem I intend to address my remarks. Now out of the whole population, 7½ millions or about 3 per cent. are scholars, though 15 per cent. or 36 millions are of the school-going age. Thus only 20 per cent. of those of the school-going age receive any education at all. Of these 7½ million scholars, about 1 million proceed to secondary education and about 40,000 reach a University career.

In judging of these figures in relation to the agricultural industry it should be borne in mind that the percentage of scholars is much higher in the urban than in the rural areas and also that a very large number of rural scholars never get more than a mere smattering of the most elementary education; so that educational efficiency in rural areas is very much lower than the official returns of general education would indicate. I may appropriately refer here to a small brochure entitled " A Policy of Rural Education " by Mr. S. H. Fremantle[1], the Collector of Allahabad, which has quite recently been published and which is well worthy of perusal. He complains how both in urban and rural schools education is too literary and how primary schools are worked for the benefit of that small section which can afford a secondary education and not in the interests of the overwhelming majority of agriculturists, most of whom abandon their studies after a few months. I think Mr. Fremantle is right. It means that very few indeed of the agricultural population get any education at all, and that, as a class, it can be put down as almost illiterate. The authorities have not been ignorant of these facts, and it is not from want of trying to improve matters that things are at such a low ebb. Much has been done in recent years to improve our system of education, especially in its relation to agriculture and the subject may be said to have received an unwonted measure of attention. In 1901 an important Conference was held at Simla presided over by Lord Curzon which led to a complete overhauling of the existing educational machinery. A policy of reform was then started, the vitalizing influence of which is felt to this day. A department of education was created with a member of council in charge. Money grants were increased and they have still further increased, as a result of keen interest taken by the present Viceroy, Lord Hardinge, who has made education a special object of his attention. Thus the total expenditure which in 1901 was 4 crores, to-day is over 10 crores. The number of pupils in 1901 was 3¾ millions, to-day it is 7½ millions. Interest has been stimulated in every quarter and expansion is noticeable in every branch.

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[1] Fremantle, S. H., *A Policy of Rural Education.* W. Newman & Co., Calcutta.

Agricultural and rural education have had quite a fair share of attention, and the need which exists for connecting the teaching of the schools with our chief industry has been and still is fully recognized. I therefore do not complain of want of endeavour. But it cannot be said that these efforts have been crowned with the success one would have wished. But if we have to admit failure, whether complete or partial, we have gained considerably by the discussions which have resulted and by the light which has been thrown on the difficulties inherent in the problem.

The occasion when agricultural education rst seriously engaged the attention of Government and the people was in 1904, when the policy for improving the agricultural industry was started by Lord Curzon. At first it was the intention to restrict efforts to improving the industry itself, but later, influenced no doubt by the examples of advanced schemes abroad, the Government elaborated a policy under which not only research and experiment, but agricultural education proper, formed an important and integral part. Large sums of money were devoted to the erection of agricultural colleges in nearly all the Provinces. Syllabuses were prepared by the Board of Agriculture and the Colleges were empowered to grant a diploma of Licentiate of Agriculture. At first, signs of success were not wanting. Candidates freely offered themselves for admission and there was found no difficulty in filling the colleges. However, as time rolled on, a decline in admissions became perceptible until the year 1913 when, in some colleges, the position became acute and the matter was brought up for consideration before the Board of Agriculture. The proceedings of the Board in that year indicate the general failure of the schemes drawn up in 1906 and 1908, and we find it expressed that the courses were found not to be suited to the class of students for which the colleges were intended, that the demand and utility for the course is obscured by its being made a road to a degree, that college graduates engaged on the subordinate staff of the Agricultural Department, with very few exceptions, failed to show any power to develop any original line, that intelligent inquisitiveness and power of independent thought was lacking,

that the course engendered too much cram and too little power of application, and so forth. What was the root-cause of this failure would appear to be explained in one of the resolutions which stated "that the general standard embodied in the Matriculation or University Entrance Examination does not provide a sufficient basis to enable a student to take full advantage of the higher instruction obtainable in the existing agricultural colleges in India"[1] and the Board recommended that a general higher education is necessary in all students admitted to such a course. In other words, it would appear that the standard of general education in the country was too low to afford suitable material with which to man colleges of such an advanced type as those which had been set up by the Agricultural Department. In fact, the colleges as educational centres were ahead of the times—primary and secondary education was too backward. Consequently the Board suggested a compromise by lowering the standard of the college curriculum to meet existing conditions and expressed its approval of a two years' preliminary practical course, which had been prepared for the agricultural college at Coimbatore as an introduction to the more advanced course. Many of the colleges have since adopted this, with the result that admissions have considerably increased. While we may expect that the Department will benefit by an increase of recruits for filling its subordinate posts, it has yet to be seen how far the education of the cultivators will be influenced by the change. My own view is that these colleges as instruments for education will not accomplish very much, for the simple reason that they are ahead of the times and that there can be no real demand on the part of the youth of the country for an advanced agricultural course until considerable progress has been made in primary and secondary education and in the improvement of agricultural methods. Not until the industry is more highly developed and the standard of living has been raised, will there arise a demand for higher education amongst the agricultural classes.

[1] *Proceedings of the Board of Agriculture in India*, 1913, p. 42. Government Printing, India, Calcutta.

The creation of agricultural colleges, however, is by no means the only effort that has been made to improve the education of our agricultural youth. Agricultural schools under the supervision of the Agricultural Department have been started in some provinces which were commended by the Board. They give considerable promise of success and, in my belief, deserve every encouragement. Also, there have been attempts in all provinces to set up a system of rural education by imparting instruction based upon the agricultural surroundings of the children, and endeavours have been made to use nature study as a means to that end. But so far the results, we must admit, have been of a microscopic character.

But there is a form of education which is not included in those I have mentioned and is unknown in India. It is a form of education which has been adopted in certain parts of America and which has of late attracted a considerable amount of attention. It is, in my humble opinion, applicable to the conditions existing in India, and offers opportunities in which officers of the Agricultural and Educational Departments could profitably combine to make the problem of education of the masses easier and more efficient. I will give a brief description.

In America general education is carried on chiefly by the Government by whom large sums of money are yearly allotted to the cause of education, but privately supported colleges are abundant and both these and Government schools are largely assisted by private benefactions, the most important of which are controlled by a private body known as the General Education Board.

Ten years ago great interest had arisen in the upraising of the Southern States whose industrial and educational conditions had fallen very much behind those of the Northern States. Conditions in the Southern States resemble in many particulars those which obtain in rural India. About 80 per cent. of the population is agricultural, depending for its livelihood almost entirely on the produce of the soil. There was great backwardness in both educational and industrial progress. Unfavourable economic conditions existed which were mainly the result of rural poverty. While the average

annual earnings of agriculturists in the Northern States were more than 1,000 dollars, those in the Southern States were as low as 150 dollars. Under the auspices of the General Education Board an enquiry was set on foot to study the educational conditions in the Southern States and to devise the ways and means for improving them. The very practical way in which the enquiry was conducted is characteristic of the American people. Surveys were planned State by State, conferences were held, monographs were prepared, dealing with the various points on the organization of education. The conclusions which resulted from this enquiry are peculiar. To quote from the Report, it "convinced the Board that no fund, however large, could, by direct gifts, contribute a system of public schools; that even if it were possible to develop a system of public schools by private gifts, it would be a positive disservice. .... The public school must represent community ideals, community initiative, and community support, even to the point of sacrifice."[1] The Board therefore resolved that assistance should be given not by foisting upon the Southern States a programme of education from outside, but by aiding them and co-operating with them in educating themselves. When, however, it proceeded to apply these principles it was faced with the following initial difficulties. They found the people had not enough money, "that adequate development could not take place until the available resources of the people were greatly enlarged. School systems could not be given to them, and they were not prosperous enough to support them." "Salaries were too low to support a teaching profession................Competent professional training could not exist; satisfactory equipment could not be provided."[2] These conditions were primarily the result of rural poverty. The great bulk of the people was not earning enough to provide good schools and the prime need was money. The Board therefore came to the conclusion that it could render no substantial educational service until the farmers could provide themselves with larger incomes.

[1] *General Education Board, An Account of its Activities*, 1902—1914. 61 Broadway, New York.

[2] *Ibid.*

and consequently they resolved that it was necessary first to improve the agriculture of the Southern States. Now mark what followed. The Board was first advised to address itself to the rising generation and to support the teaching of agriculture in the common schools. But after thoughtful consideration this plan was rejected. They found that in the absence of trained teachers, the effort was impracticable; moreover, there were no funds with which to pay such teachers, and the instruction itself would not materially contribute to its own support. Finally, it was impossible to force intelligent agricultural instruction upon schools whose patrons were not themselves alive to the deficiencies of their own agricultural methods. Until the public was convinced of the feasibility of superior and more productive methods the public schools could not be reconstructed; once the public was convinced and, by reason thereof, better able to stand the increased cost, the schools would naturally and inevitably re-adjust themselves.

"It was therefore deliberately decided to undertake the agricultural education not of the future farmer, but of the present farmer, on the theory that, if he could be substantially helped, he would gladly support better schools in more and more liberal fashion."[1] The Board, therefore, set about an extensive enquiry as to the best means of conveying to the average working farmer of the South, in his manhood, the most efficient known methods of intelligent farming. As a result of this enquiry a movement known as the Co-operative Farm Demonstration was set up. A year was spent in discovering the most effective methods of teaching improved agricultural methods to adult farmers. Dr. Seaman Knapp of the United States Department of Agriculture was engaged to show farmers how to improve their agricultural methods and raise the standard of their industry. It was not long before successful results were obtained. Under improved treatment it may be roughly stated that the crop yields were doubled. Thus in 1909 the average yield in pounds of seed cotton was 503·6 per acre: on demonstration farms the average was 906·1 pounds; in 1910

[1] *General Education Board. An Account of its Activities*, 1902—1914.

the figures were 512·1 and 858·9 respectively; in 1911, 624·6 and 1081·8; and in 1912, 579·6 and 1054·8.

In the growing of corn similar results were obtained. In 1909 the ordinary average yield was 16·7 bushels per acre, while on the demonstration farms it was 31·7 bushels per acre. In 1910, 19·3 and 35·3, in 1911, 15·8 and 33·2, and in 1912, 19·6 and 35·4. It is further stated that the poorer the season, the more clearly did the demonstration methods prove their superiority. The work was also studied from the standpoint of the farmer's financial profit. "In Alabama, for example, in 1912, the average yield of lint cotton was 173 pounds per acre; but demonstration acres averaged 428·3 pounds. Demonstration methods, therefore, netted the farmer 255·3 pounds per acre. At the average price of 65 dollars a bale for lint and seed, the farmer made an extra 33 dollars per acre; as there were 8,221 acres under cultivation on the demonstration methods, the total gain was 271,000 dollars. In the same year 7,402 acres were under cultivation in demonstration corn. Demonstration acres averaged 26·9 bushels more per acre than the general average for the State. The demonstration farmers of the State pocketed 139,379·66 in consequence."[1] This was of course in one State alone. These methods have not been restricted to cotton and corn, but have been applied to a very large number of crops and the propaganda is not limited to cultural methods, but is applied equally to the improvement in farm equipment, more comfortable houses, better barns, stronger teams, better implements, and cleaner and healthier surroundings. Hence it is claimed that the beneficent results of this work are not limited to financial profit and cannot entirely be measured by money. Characteristic examples of the relief which the new system brought are cited, but one example will suffice. In Mississippi 5 years ago the value of a certain farmer's produce was one dollar per acre and he was 800 dollars in debt. In 1909 his entire farm was worked under the Government method. He averaged 1,100 lb. of cotton against his neighbour's 300 to 400 lb. He made besides 500 bushels of corn and from one

[1] *Ibid.*

special demonstration acre realized 152 barrels of high class seed which he sold for 300 dollars. His debts are now paid and he has cash in the bank. So much for the education of the adult farmer. We now come to the effect this movement has had on the education of youth. We are told that the initiation of demonstration work and the application of the principle of co-operation has resulted in the disappearance of the disorganization characteristic of rural life. Colleges of agriculture, farmers' institutes, agricultural high schools, "Boys' Corn Clubs," "Girls' Canning and Poultry Clubs," and the like have been brought into existence where practically none of these things existed before, and that the social and educational awakening of the rural South is recognized as being a bye-product of the demonstration movement. Statistics show that the provision for schools has steadily increased. Thus the expenditure for public, elementary, and secondary schools in North Carolina which was 1,091,226 dollars in 1901, is 4,300,000 in 1913. In South Carolina the expenditure which was 961,897 dollars in 1901 is 2,609,766 in 1913, Arkansas 1,369,809 and 4,279,478, and so forth. These instances give but meagre examples of the important results achieved by the demonstration movement. For greater detail I must refer you to the Report[1] itself.

I think you will agree with me that the educational policy I have described is novel and peculiar. When I say novel, I do not mean that demonstration work has not been used before among farmers and cultivators. We all know that it has, but it is novel in the sense, that never before, so far as I am aware, has demonstration been used in any country as a force and weapon for education so as to make it a condition precedent to the education of youth. It is a new experiment but a new experiment of a remarkable kind. The results indicate that it is no use to try and educate youth if you do not first secure the welfare of the community to which it belongs and that therefore the development of resources should precede education in order of time. What the American General Board of Education says to the farmer in the Southern States is—You

[1] *Ibid.*

are too poor to supply your sons with education; we could assist you, but we do not consider it proper to do so, unless you yourselves contribute. As you cannot do this, we will assist you to increase your earnings so that you will be in a position to provide yourself with schools. When you have done this we will assist you further. We consider that it would be wrong for us to directly educate the rising generation, if you are not able to participate; in fact, we believe that it would be a positive disservice for us to do so. Your schools should be started by yourselves, they should represent community ideals, community initiative, and community support even to the point of sacrifice.

We have seen how the experiment has succeeded. Might we not with advantage apply the same principles to India? Might we not invite the co-operation of the Agricultural Department in a general scheme and policy of education? Is there any likelihood of success without this? Can we hope to give the youth of this country an adequate educational service unless we go to the root of things, like the Americans have done, and enlist and increase the activities of the Agricultural Department in enlarging the resources of the cultivator and thus build our educational system on the increased prosperity of the agricultural classes? These are the questions I desire to offer for consideration. India is in no better position than the Southern States were ten years ago. Indeed I think we may safely assert it is in a far worse position. The average earnings of individuals in the Southern States at that time were 150 dollars. In India, according to some authorities, under the most optimistic calculations, they are as low as Rs. 30 per head. You must agree this gives little or no scope for self-help. It therefore seems to me plain that under present conditions we cannot expect the country to supply itself with the means for an advanced system of education. Nor can Government be expected to do so, for Government's resources are limited and depend upon taxation, and that in turn depends upon the ability of the people to be taxed. All Government can do is merely to touch the fringe of the problem and supply a modicum of education; it cannot afford to do more. Mr. Fremantle very well describes the situation when he says: "We

should surely pause to consider whether the time is ripe for the introduction of a system of general primary education into rural areas. It is a question whether we are not beginning at the wrong end and whether primary education can make any real advance before there is a substantial improvement in economic conditions."[1] These are words which the devotees at the shrine of the policy of free education for the masses might with advantage ponder.

The question then is whether we can, in any way, make the principles which have been so successfully applied in America, applicable to India. My belief is that we can. We have practically the same conditions here as obtained in the Southern States ten years ago. If anything, as I have shown, they are a good deal worse. But this is no argument against their adoption. Rather the reverse, for the lower the degree of prosperity, the greater is the need for increasing it. Already in the Provinces a great deal has been done by the Agricultural Department in the way of demonstration of the character described and utilized by the American Board of Education. But it does not go far enough. It, however, forms a nucleus on which to expand and might well be used as a beginning. The work is on the right lines. But we require to do more. We want more men, more money, wider organization; but, above all, we require the recognition amongst all classes that in this work lies the germ of future progress. This is a point which is not generally recognized, or, if so, it is certainly not acted upon. While the money spent to-day on education is over 10 crores of rupees, that on agricultural development is only 50 lakhs. That shows that we have not yet got to view these two important problems in their right perspective, and do not fully realize the important relation which agriculture bears to education. Many think that the development of agriculture depends on education, and we gave effect to that view when we started our agricultural colleges. But would it not seem that the truth lies in the opposite direction, and that in a backward country like India the advance of education is really dependent on the development of agriculture, and that the best form of education

[1] "A Policy of Rural Education," W. Newman & Co., Calcutta.

you can give to the rural classes under existing circumstances is demonstration in improved agricultural methods? It was found to be so in the Southern States of America and we have no reason to suppose it is otherwise in India. To carry out the idea it is not necessary to bring our present educational policy to an end. I would not propose anything so revolutionary. Government must, as I have already explained, supply a modicum of literary teaching and this must continue, but it would be an immense improvement if the Agricultural Department were called in to co-operate and demonstration were given a large share in the general scheme of education.

We could not be expected at first to progress with the same degree of rapidity as in America, because we have to do a large amount of research and experiment before we can demonstrate improved methods on a large scale. In America the advanced stage in the agricultural development of the Northern States supplied ready at hand the stock-in-trade required for at once setting in motion the demonstration movement in the backward Southern States. We are not so forward. Still we have achieved enough with our small band of workers to show that the same kind of work can be done out here and that all we require is expansion. Given the means for this (and who will say it would be a bad investment?) and a recognition of demonstration as an integral part of a general scheme of education, and I feel sure we shall, by such a policy, lay the best and securest foundations for the advancement of education as well as of the prosperity of the people.

THE APPLICATION OF BOTANICAL SCIENCE TO AGRICULTURE.

BY

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I. Introduction.

A study of the literature dealing with agriculture indicates that there is some confusion of ideas as to the precise relation which exists between the science of botany on the one hand and the practice of agriculture on the other. In the present paper, an attempt has been made to define the bearing of the scientific aspect of the vegetable kingdom on the economic development of crop-production and to show how a knowledge of this science can best be applied to agricultural problems. A new term has recently grown up—Agricultural Botany—and text-books have appeared thereon as if a new branch of the science had been developed. Agricultural botany is supposed to be easier than ordinary botany and to be more adapted to the needs of the students in agricultural colleges. It is often assumed that in such colleges only a rudimentary knowledge of botany is required and that the examples used in teaching must of necessity be taken from cultivated crops. It is even thought that students trained in this manner will develop into investigators and that advances in agriculture can be achieved by such agency. I venture to assert that nothing could be further from the truth and that, in this direction, there is no royal road to success and that the final result of such endeavours can only be disappointment. For any real advance to be made in crop-production, a thorough scientific knowledge of botany in all its branches is one of the first

conditions of progress. This will be clear if the real problems to be solved are considered in all their bearings.

The attempt to improve cultivated crops by scientific methods is a recent development and can be traced to two main causes—(1) the gradual recognition of the fact that in agriculture the plant is the centre of the subject; and (2) the rapid rise of the study of genetics which followed the re-discovery of Mendel's results in inheritance.

Starting from Liebig's application of chemistry to agriculture, an enormous amount of chemical investigation, relating to the composition of the soil and of the plant, took place and for a time great hopes were entertained that in this direction important progress could be made. These expectations were not fulfilled, and gradually the chemists broadened the basis of their investigations and took into consideration the physical character of the soil, its geological origin, and the natural vegetation found growing therein. In this manner, modern soil-surveys have arisen in which the importance of the plant as a living organism has been slowly recognized. Recently, the development of genetics has drawn still more attention to the plant and this recognition is reflected in the present constitution of the staffs of up-to-date Experiment Stations. Side by side with these changes, the studies of disease in plants have to some extent receded in importance as is well seen if the present staff of the Bureau of Plant Industry of the United States Department of Agriculture is compared with that of twenty years ago when this Bureau was almost entirely composed of mycologists and when the advice given by the botanists was largely confined to the treatment of plant diseases.

The importance of the plant in crop-production may be said to be generally recognized at the present time. A large number of botanists are being employed at Experiment Stations and the public have often been led to expect that a revolution is about to take place, particularly through the application of what is popularly known as Mendelism. A critical examination of the literature discloses some signs that these extravagant hopes are not likely to be fulfilled, not that these hopes are impossible but rather because the problems

have not always been taken up on a *sufficiently broad basis and attacked simultaneously from several standpoints.*

II. The Development of Botany.

A brief review of the manner in which botanical science has developed will help to make clear the great difficulties which must first be surmounted before any results of real practical value can be obtained.

As is well known, the origins of modern botany are to be traced to the old herbals of the sixteenth and seventeenth centuries and to a period when plants were studied chiefly from the medicinal point of view. It was then essentially a field study out of which the modern ideas on classification slowly emerged. The development of the microscope, while leading to immediate and far-reaching advances, necessarily focussed the attention of investigators on the anatomy of plant organs and on the study of the various structures met with in these researches. Similar particularist tendencies arose in the growth of systematic botany and undue attention was often paid to the study of the floras of various regions from the point of view of herbarium specimens alone. The growth of physiology was too slow to remove entirely the evils of a somewhat formal and one-sided development which was reflected both in teaching and research. Physiological investigations are notoriously difficult and the greatest patience and skill are necessary in advancing our knowledge of the various functions in the plant. The manner in which botanical science has developed and the necessity of dealing with large classes of students in Universities, have necessitated a somewhat formal presentation of the subject in separate sections such as morphology, anatomy, physiology, and systematy. Much of this sub-division is inevitable but it renders difficult a proper conception of the plant as a living whole, as a complex factory which takes in, by way of the roots, various mineral salts in solution in water and, by the leaves, oxygen and carbon dioxide from the air, working all these raw materials up into complex food substances by means of energy focussed from the sun through the medium of the chlorophyl corpuscles. The plant is continually manufacturing

new food, developing new organs, and completing its life cycle under constantly varying conditions as regards moisture, food materials, temperature, humidity, and illumination. The vegetable kingdom is like a multitude of exceedingly complicated and competing hostile factories which have to carry on their activities under all sorts of rapidly varying circumstances. Any failure to meet the changes in the working conditions, caused by weather or by shortage of water and mineral salts in the soil, may mean the stoppage of the factory and the extinction of the organism. In this competition, all the combatants are armed to the teeth and possess all kinds of devices to assist in the struggle for existence. If any space in the sun is yielded by one of the competing factories, it is instantly seized by the rest. The limitation of armaments is an impossible conception in the vegetable kingdom. It is no easy task for the student to appreciate fully the many-sided aspects of the living plant and to master the manifold details of a science, still to a large extent in the descriptive phase of development, particularly when that subject is presented to him in parts often very loosely bound together. The investigator too is hampered in this direction by the necessity of specialization and of narrowing down the conditions of a problem so that the ordinary clear cut methods of academic research can be applied. It requires a conscious mental effort on the part of a botanist to regard the vegetable kingdom as a whole and not to think of it only in terms of systematy, physiology, or of anatomy. Training in research in any particular branch does not necessarily widen the general outlook, although it is of the greatest use in other ways.

The more recent developments in botanical science are fortunately all tending to a study of the plant as a living whole. Both the scientific study in the field of plant associations (ecology) and the systematic examination of the various generations of plants raised from parents which breed true (genetics) are doing much to mitigate the evils which follow from undue devotion to purely laboratory work. Ecology and genetics are taking the botanist into the field and will, in all probability, materially influence the future development of the science. This will be all to the good and

should do much both to raise the standard of and emphasize the importance of field work and also develop the natural history side of botany. The botany of the future is likely to combine all that is valuable in laboratory work with modern ideas on ecology, classification, and genetics.

III. The Relation of Botany to Agriculture.

We have seen that from the nature of the subject and arising out of their training, most botanists experience difficulty in realizing fully the plant as a living whole in which one part reacts on another. A wide scientific outlook on the many aspects of plant life is nevertheless the first condition in applying botanical science to practical problems. It is, however, by no means the only one. The next step for the botanist is to study his crop in the field and to learn to appreciate the agricultural aspects of crop-production. In other words, he must study the art of agriculture as applied to his particular problem. Too much stress cannot be laid on this. The investigator must himself be able to grow his crop to perfection and it is not too much to say that no real progress can be made without this. The ordinary agricultural processes applied to any crop bear a direct relationship to the physiological necessities of the plant and have been evolved from centuries of traditional experience. Thus in the growth of *rahar* (*Cajanus indicus*) in many parts of India, it is the custom to dig the land at the end of the monsoon as by this means the yield is increased. The physiological basis of this operation is the necessity for the provision of abundant air for the root-nodules in an alluvial soil consolidated by heavy monsoon rainfall. Indeed the agricultural processes necessary to grow a crop to perfection in India are nothing more than lessons in physiology learnt by experience through a long period of time. In all investigations on crops, a first-hand knowledge of practice is necessary and nowhere is it so important as in plant-breeding work where practice is quite as valuable as an acquaintance with the methods and results of genetics. The greatest devotion to the study of inheritance, using for this purpose material indifferently grown, is largely labour lost as many characters are masked unless the plants are really

thriving and well-developed. For instance in wheat, the red colour of the chaff never develops in badly grown plants thereby causing great confusion in systematic and breeding work on this crop. In tobacco, the various leaf characters are almost entirely masked by bad cultivation and their inheritance can only be studied if the crop is grown to perfection.

The investigator, after having learnt how to grow plants and having mastered agriculture as an art, must proceed to study his crops in the field. It is not sufficient to plant the seed and wait till flowering time and harvest come round for the results. Daily contemplation of the growing crop and observation of the plant through its whole life-history will suggest many new ideas and do much to train the observer, and develop the power of accurate deduction and real agricultural insight. In variety trials and field experiments, the necessity of constant observation of the growing crop is seldom recognized. An even plot of land is selected, the crop is sown and the harvest weighed. Should the season be abnormal, this circumstance is often recorded. It is somewhat dimly perceived that the quantitative results of any year partake of the nature of an accident, but it is thought that a repetition of the experiment for, say, fifty to one hundred years and the striking of an average result will remove most of the effects of disturbing factors. It is true that this expensive and time-consuming procedure will give the mean result under the conditions of the experiment provided all due care is taken in carrying out the work. On the other hand, a constant observation of the growing crop by a fully qualified observer will lead to the deduction of the factors on which yield depends far more rapidly and accurately than can be done by such a mechanical method. Constant observation of the growing crop is therefore of the first importance. In course of time, the observer learns how to read his practice in the plant and, at the same time, he develops from hardly won experience a sympathy and understanding of the cultivator and of the grower's point of view. The raising of crops is a most useful discipline for a young investigator fresh from the university, and it also serves rapidly to remove any intellectual arrogance he may possess in his attitude

towards the farmer or cultivator. First-hand practical experience will thus assist towards producing a proper relationship between the scientist on the one hand, and the practical man on the other. This apprenticeship will, at the same time, serve to eliminate at the outset men who lack a practical turn of mind. The agricultural public judges largely by eye, and is not trained in the rapid digestion and understanding of printed reports. Well grown crops at an experiment station are much more telling than printed bulletins however well-illustrated these may be. In dealing with the would-be improver, the attitude of the agriculturist is often one of amused scepticism as, among themselves, deeds always count much more than words and the benefits of education are not always regarded with enthusiasm. "Show me thy cultivation and I will tell thee what thou art" is merely putting into words the view of the country-side towards a new arrival in its midst. The agricultural investigator must also pass through this ordeal with credit to himself before he can hope to establish his position and hold his own with the tillers of the soil.

Science and practice must be combined in the investigator who must himself strike a correct balance between the two. The ideal point of view of the improver is to recognize agriculture as an art which can best be developed by that instrument called science. Once this is fully realized and acted upon, the place of the experiment station in agriculture will be understood as a matter of course and the qualifications needed by the workers will be self-evident. There will be little or no progress if practical agriculturists are associated with pure scientists in economic investigations. This has often been tried and has never yielded results of any importance. The reason why such co-operation fails is that without an appreciation of practice, the scientist himself never gets to the real heart of the problem. The history of the indigo investigations in India is a very good case in point. During the last 20 years, a number of scientists have been employed in an endeavour to improve the production of natural indigo. Over £50,000 have been expended on this work between 1898 and 1913 but no results have been obtained, largely because the scientists preferred to engage European

assistants on indigo estates to grow their experimental crops rather than to cultivate them themselves. The result was that the real problems were not discovered, a large amount of ineffective work was done and valuable time was lost during which the natural indigo industry declined and the synthetic product rapidly established itself in the markets of the world. The solution of the indigo problem has recently been disclosed by a study of the plant in the field. It is not too much to say that if a properly qualified botanist with a knowledge of agriculture had attacked the indigo problem twenty years ago, the history of this industry would have been very different.

There remains for consideration the commercial aspect of investigations on crops and the necessity, on the part of the worker, of keeping in close touch with the requirements of the trade. Particularly is this important in the case of materials used in textile industries like cotton where any marked alteration in the raw product might easily involve extensive changes in machinery. In the case of cereals like wheat, it is necessary in improving the variety to follow closely the needs of the manufacturer and to ensure that any new types introduced into general cultivation can be milled to advantage. If grain quality, of increased commercial value, can be secured as well as higher yielding power, the combination is all to the good. The investigator must therefore study trade requirements and be able to make use of the experience and knowledge of the men who handle and use produce on the large scale. The successful merchant often possesses information which is of the greatest value to the botanist and which helps the investigator to perceive the manner in which an improvement can most effectivel be made. Just as the success of a commercial man depends on his ability to determine the direction in which he can improve his method or his product above those of his competitors, so the investigator must possess a similar practical instinct. He must be able rapidly and unerringly to decide in which direction the maximum improvement is possible.

That a combination of science, practice, and business ability in the same individual is essential in all agricultural investigations

dealing with the plant will be evident if the kind of problem awaiting solution is considered in detail. Many of these questions fall into the following three classes :—

(1) *Improvements in the efficiency of the plant.* If we regard the plant as a factory and a crop as a number of factories, the aim of the grower is to produce the largest possible output of some plant product—seed, leaves, roots, stems, or flowers. In stimulating a crop to produce the maximum in any one direction, the factory as a whole must be considered and the machinery must not be thrown out of gear. The physiological aspects of growth must be clearly kept in mind as well as the conditions under which the translocation of reserve foodstuffs takes place. We can, for example, often increase the yield of leaf in a crop like tobacco by suitable manurial treatment such as a copious supply of nitrogenous food material, but the resulting loss in quality is so great that the extra weight would result in financial loss. We should merely produce in this way badly ripened leaves in which the proper development of colour and flavour during curing would be impossible. Any attempt to increase the output of a crop can only be successful if the physiology of the plant is considered together with the economic aspects of production. Such problems have to be solved within the working conditions of the plant factory and also within the general economic limits imposed by labour and capital. In such matters, the investigator might easily go astray unless he keeps the laws of plant physiology in view and unless he is fortified by a knowledge of practice and an appreciation of the general working conditions.

(2) *The treatment of disease.* The inadequacy of much of the experiment station work on the diseases of plants, in which fungi and insects are concerned, has recently been referred to by Professor Bateson[1] in one of the sectional addresses to the British Association :—

"Nowhere is the need for wide views of our problems more evident than in the study of plant diseases. Hitherto, this side

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[1] *Report of the British Association for the Advancement of Science*, 1911, p. 590.

of agriculture and of horticulture, though full of possibilities for the introduction of scientific method, has been examined only in the crudest and most empirical fashion. To name the disease, to burn the affected plants, and to ply the crop with all the sprays and washes in succession ought not to be regarded as the utmost that science can attempt. There is at the present time hardly any comprehensive study of the morbid physiology of plants comparable with that which has been so greatly developed in application to animals. The nature of the resistance to disease, characteristic of so many varieties, and the methods by which it may be ensured, offer a most attractive field for research, but it is one in which the advance must be made by the development of pure science, and those who engage in it must be prepared for a long period of labour without ostensible practical results."

A diseased condition in a plant usually arises from some profound interference with the normal physiological processes after which a pathological phase gradually develops. The protoplasm and cell-sap become charged with waste products and a parasitic fungus is then able to destroy the tissues. An invasion of fungus mycelium is usually impossible when the plant is in health as protoplasm is strong enough to resist any attack and the cell-sap is not in a suitable condition to nourish the fungus. The parasitic fungus and the destructive insect are often consequences rather than the real causes of disease and are merely the last phase in the death of a moribund organism. The Java indigo crop in Bihar[1] has recently furnished an interesting example of the necessity of a wide outlook in the investigation and treatment of plant diseases. A diseased condition, known locally as *wilt*, began to make its appearance some years ago after which it rapidly spread all over Bihar. About the middle of the monsoon, the plants were observed to drop a good deal of leaf and the remaining foliage was seen to change in appearance, becoming a greyish, slaty colour. Growth finally ceased after which the plants slowly died during October and November. Not only was

[1] Howard and Howard, *The Improvement of Indigo in Bihar*, Bulletins 51 and 54, Agricultural Research Institute, Pusa.

the yield of dye seriously reduced, but the affected plants yielded hardly any seed. For this reason, the area under Java indigo in Bihar rapidly fell from 70,000 bighas in 1910 to about 15,000 bighas in 1913. Investigation of this disease yielded no results, and it was found that none of the insects, fungi, or bacteria associated with the affected plants were responsible for the trouble. For the moment, science seemed entirely at a loss in suggesting any practicable means by which the final extinction of the indigo industry could be prevented. In reality, however, the position was in no respect hopeless. Examination of the affected crop showed that the leaf-fall and wilt were connected with the destruction of the active root-system of the plant, including the nodules, as a result of interference with the air-supply of the roots brought about by a constantly wet condition of the soil during the long monsoon phase. The wilt disease was found to be the last stage in starvation caused by the cutting off of the supply of one of the essential raw materials—air—needed by the roots and root-nodules. Evidently the line of attack lay in the direction of increasing the air-supply in the soil and in assisting the plant to withstand the constantly moist soil conditions which set in during the monsoon. This was done by improving the methods of cultivation during the hot weather and by the provision of surface drainage, by which each field was cut off from the run-off of other areas by a suitable arrangement of trenches. The problem of the seed supply was solved by August sowings on high-lying, well-drained fields. In this manner, the plants were able to withstand the wet soil conditions of the second half of the monsoon without injury and to yield fine crops of excellent seed. The yield of dye was materially increased by thorough cultivation in the hot weather combined with surface drainage. The history of the indigo disease in Bihar furnishes a very good example of the necessity of a broad outlook in dealing with diseases of crops and for regarding the plant as a complex factory in which injury to any one part often upsets the whole machinery.

(3) *The creation of improved varieties.* In the development of an industry like the manufacture of cotton cloth from the raw material, there is, as is well known, a constant substitution of the

existing machinery by improved types and the scrapping of old plant is continually taking place. In like manner in agricultural development, the substitution of existing varieties by improved forms is constantly being carried out, and in many European crops the varieties grown a hundred years ago have almost disappeared. In crop-production, as in cotton factories, the size of the scrap-heap is one of the indications of the rate of progress. The creator of new varieties of plants must obviously be even better fitted for his task than the engineer who improves spinning and weaving machinery. In a cotton factory, improvement can be made in detail· whereas, in the plant, the whole factory must be replaced by a new one and the variety changed. To develop an improved variety and to utilize botanical science to the best advantage, it is clear that the problem to be attacked must first be understood in all its bearings. We require to know by experience the general agricultural conditions of the tract in which the improved variety is to be grown, the kinds at present cultivated, the directions in which improvements are possible, and where the greatest economic advantage can be obtained. In other words, the problem must be simultaneously considered both from the standpoint of the cultivator and from the point of view of the trade. An understanding of the needs of the crop and a knowledge of systematy and genetics must be combined with the insight of the inventor. In such work, no possible scientific method can succeed without the intuition of the breeder. Any attempt to measure or record the characters of large numbers of plants and to obtain the final selections by a scientific system of marks is hopeless, as the investigator would be speedily swamped by the volume of his material. The insight of the breeder is necessary for the work and the judgment, which comes by practice, in the rapid summing up of essentials by eye is far more useful than the most carefully compiled records or any system of score cards. The successful plant breeder is to a large extent born and not made as is proved by the fact that without the aid of science great advances have been made in the breeding of stock, cereals, and in various branches of horticulture. Science helps the born breeder by providing him with new and better instruments and, by bringing knowledge to bear

from many sides, it accelerates the output and lightens the work in a multitude of ways.

In the limits of this paper, an attempt has been made to indicate the class of problems in plant-production which await solution if progress in agriculture is to be obtained by the aid of botanical science. These problems are not simple, and often cannot be solved by the ordinary methods of academic research. Many of them can, however, be dealt with successfully if attacked simultaneously from several standpoints provided always that the investigators themselves are fully qualified for the work. As far as crops are concerned, progress can best be made by botanists, well grounded in pure science, who, at the same time, possess sufficient aptitude to master agriculture as an art and who also have the type of mind to be found in the successful inventor. In this direction, the field of work in the Empire is almost unlimited and the great universities, by helping to train the investigators of the coming generation, have a truly Imperial task to perform. Failure on the part of individuals will occur in the future as in the past, but one great cause of want of success will be removed if the all-importance of agriculture as an art in the equipment of the next generation of experiment station workers is recognized by all concerned. The State can do much in these matters by a practical recognition of the principle that the labourer is worthy of his hire and that the man, who makes two blades of grass grow where one grew before, deserves well of his country, and must be promptly and adequately remunerated.

IMPORTANCE OF SOIL-AERATION IN FORESTRY

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Forest officers have long realized the importance of soil-aeration in Forestry in so far as this is connoted by such general expressions as "the physical condition of the soil," "water-logging," and so forth. The aspect of this question dealt with in the present paper, however, is one which has not yet attracted the attention it deserves, *viz.*, the damage that may be done to the seedlings of our forest trees by insufficient soil-aeration when the physical condition of the soil is apparently suitable for growth and when the soil, although moist, is far from being saturated with water. The results noted in this paper refer, it is true, to a single species only, *viz.*, the *sal* tree, *Shorea robusta*, but it is believed that they will be found to apply to a number of other species.

The seedling reproduction of *sal* in our Indian forests is by no means satisfactory. In many forests where conditions seem favourable no seedlings exist, and in others the seedlings die back for several years. Plate 1, fig. 1 shows examples of *sal* seedlings which have died back for several years and which are typical of the majority of those found in the protected forests of Northern India. Note the thickened rootstocks and comparatively feeble shoot development. This dying back is usually considered to be due to drought. The whole plant here dies annually with the exception of the stout portion just below the ground level which persists and gradually increases in size and length until finally a persistent aerial shoot is also developed. This delay in the establishment of seedlings interferes with the economic management of our forests and entails a financial

sacrifice in the loss of several years' increment. Drought, however, obviously cannot explain why seedlings frequently die wholesale during the rains nor why the dying-back is frequently more marked in the moist soil of the shady forest than in the drier soil in the open.

The following results dealing with the causes of the death and dying-back of *sal* seedlings have now been established by work recently carried out at Dehra Dun :—

(1) Seedlings grown under favourable conditions of soil and moisture in the Dehra garden do not, as a rule, die back. A few weakly individuals do die back, but the majority produce vigorous shoots which persist from the first and attain an average height of 13″ in one year and 26″ in two years.

Plate I, fig. 2 shows such seedlings one year old and also some weakly plants of the same age which have died back. These vigorous garden plants indicated the development which was possible under the local climatic conditions and the chief object of the present work was to attain or approach this ideal in the local forests.

(2) An experiment carried out in the Dehra garden, in 1913, showed that, if rain water was allowed to accumulate in non-porous pots, in which the basal drainage holes were tightly corked, and which were filled with the local *sal*-forest soil, the latter was soon rendered entirely unsuitable for the growth of *sal* seedlings, although it was by no means saturated with water. It was found that, under these conditions, 100 per cent. of *sal* seedlings were either killed or had their roots extensively rotted when the water-free air-space in contact with their roots was maintained at 450 c. ins. per c. ft. of soil, or less, for a period of 6 weeks, while seedlings in the same soil, in similar pots, but which were uncorked, remained healthy. This experiment was repeated in 1915 with practically the same results.

Plate II shows the appearance of the seedlings in these pots in September 1915. Note the healthy plants

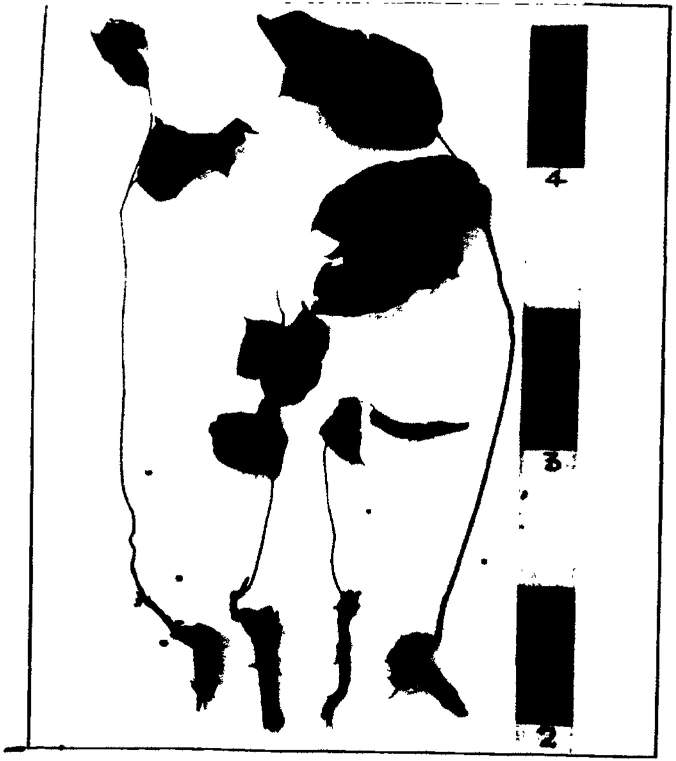
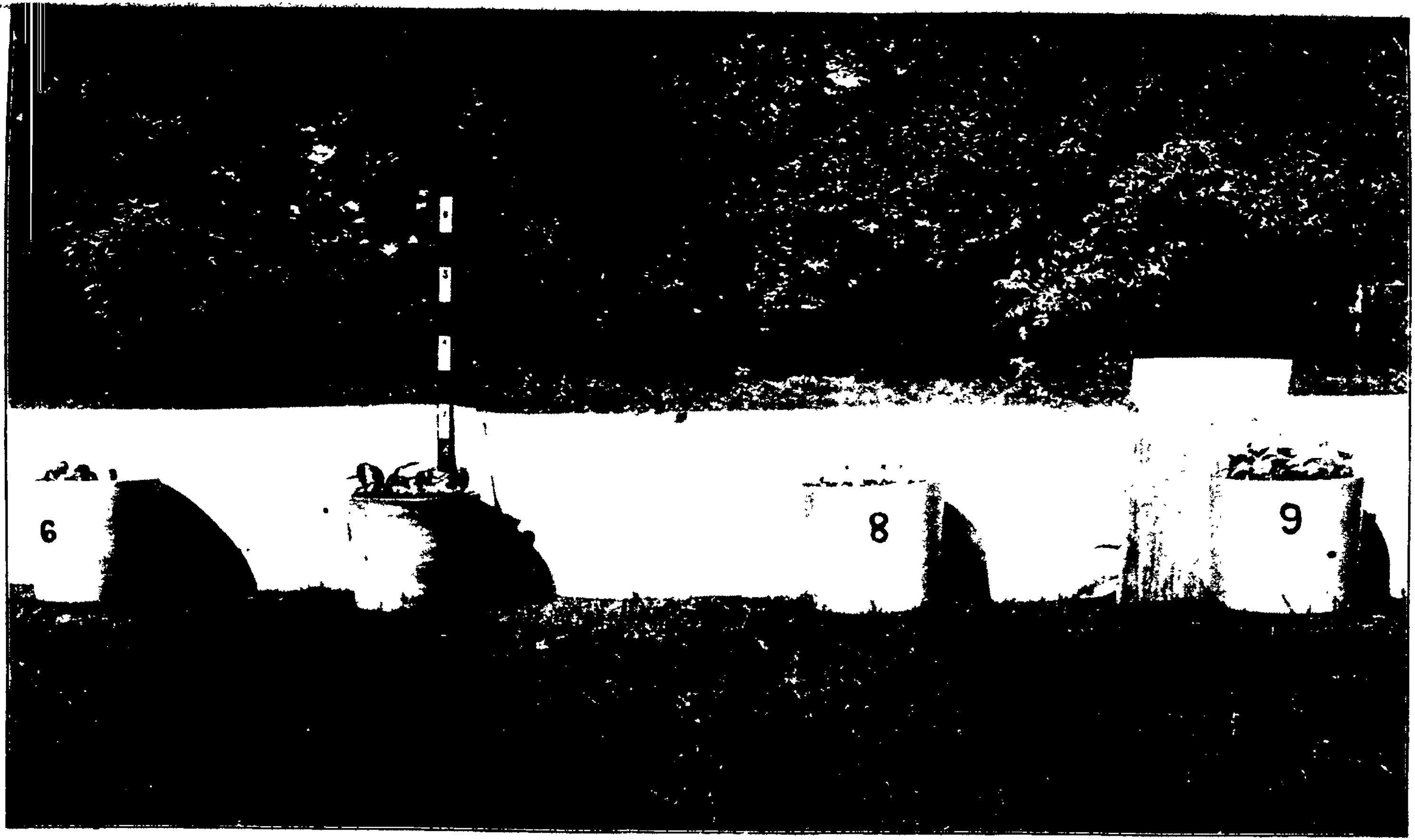


Fig. 1.

Sal seedlings typical ot those found in the protected Dehra Dun forests. These have greatly thickened rootstocks and ha e died back for several years. The measuring staff appearing in this and the subsequent figures shows lengths of 6 inche alternately black and e.

Fi g. 2.

Sal seedlings, 1 year-old, grown under favourable conditions of soil and moisture in Dehra Dun Experimental Garden. The five small plants have died back. The majority of the plants, however, do not die back under these conditions and the four large specimens are typical of these. Such vigorous plants attain an average height of 13. 6 inches, in 1 year and 26 inches, in 2 years. This may be regarded as the ideal seedling development possible in the locality.



Photograph taken 20th September 1915, showing *Sal* seedlings growing in *Sal* forest loam. Note the healthy growth in the uncorked pots 7 and 9 as compared with that in pots 6 and 8 which were corked on 30th July 1915.

in the uncorked pots 7 and 9 as compared with those in the corked pots 6 and 8.

This strongly injurious effect on *sal* seedlings of a constantly moist condition in loam was also obtained in an earlier experiment in which good basal drainage was provided, but in which the soil was kept constantly moist by merely diminishing the evaporation from the surface.

(3) Sowings in 1912-13 in sample plots in the shade of the local *sal* forests and on similar soil in the open outside the forests, respectively, resulted at the end of the first rains in 7 per cent. and 37 per cent., respectively, of healthy plants, calculated on the number of seeds sown. Similar sowings in the following year resulted in 17 per cent. and 86 per cent., respectively, of healthy plants. In these experiments the death of the large number of seedlings in the shade was preceded by more or less extensive rotting of the root. During the rains of 1912 the surface soil of the shade plots did not contain more than 400 c. ins. of water-free air-space per c. ft. of soil, whereas the soil of the open plots contained considerably less water and more water-free air-space. It will also be seen that, in the shade plots, the water-free air-space was actually less than has been proved to be highly injurious in the same soil in non-porous pots. In the dry season following the rains of 1912 more seedlings died of drought, during the months of least rainfall, in the shade than in the open plots. This was explained by the fact that, although there was practically no difference in the soil-water-content of the open and shade plots, respectively, at a depth of 3–9″ during this period, the roots in the shade had attained, by May 1913, an average length of 6″ only, as against an average length of 18″ in the open. The plants in the open, therefore, having their roots in the deeper moister soil layers were comparatively safe from damage by drought.

Plate III, fig. 1 shows a typical shade plot at the close of this experiment in July 1915. Notice the absence of vigorous seedlings in the seed-bed. Plate III, fig. 2, on the other hand, shows one of the open plots in the same month. Note the numerous healthy plants.

(4) Sowings, in 1913, in large pots filled, some with clean sand alone and others with a mixture of clean sand and dead *sal* leaves, which were sunk in one of the shade plots of the previous experiment resulted in a percentage of 82 healthy plants at the close of the first rains, as compared with 62 per cent. obtained in the adjacent soil from which the dead leaves and humus had been cleared for two years and 16 per cent. obtained in the same soil with which dead *sal* leaves had been mixed. The root development in the sand was also materially better than that in the adjacent soil. As the plants, in this experiment, were exposed to practically identical conditions of light, temperature, and air-humidity, this indicates that the unsatisfactory development of seedlings in the shady forest is primarily due to a soil factor and not to deficient light, unsuitable air-temperature, or air-humidity; also that the injurious effect is increased by an admixture of dead *sal* leaves with the forest soil and is inoperative in a well drained sand even when dead *sal* leaves are mixed with it. Other experiments have indicated that the effect of this soil factor is progressively diminished by repeated working of the soil coupled with removal of the humus.

With reference to the chief object of the present work, *viz.*, the establishment of vigorous seedlings in the local forests, the experiments detailed above indicated :—

(1) that an injurious soil factor was chiefly responsible for the unsatisfactory seedling development by causing high mortality during the rains and subsequently a high percentage of deaths from drought owing to poor root development;

Fig. 1.

Forest shade plot XI. Photograph taken 20th July 1915, 2 years after sowing. Note the absence of vigorous seedlings in the seed-bed.

Fig. 2.

Forest plot VIII, in the open. Photograph taken 20th July 1915 Note the numerous healthy 2-years-old seedlings surviving in the plot.

(2) that this soil factor could be put out of action by sufficiently good soil-aeration.

It appeared probable, therefore, that clearing the forest growth and exposing the soil freely to sun and air would produce the soil conditions necessary for successful growth, provided that the area cleared was sufficiently small to ensure the light side-shade necessary in Northern India for protection from frost. In 1913, therefore, two adjacent sample plots were selected in a portion of the Dehra forests where sowings in the previous year had given unsatisfactory results.

Above one plot, the overhead cover was entirely removed, before sowing, by felling all trees above and in the immediate neighbourhood of the plot, the total cleared space having a diameter of 60 ft. or a little less than the height of the surrounding trees. In the adjacent shade plot the cover was kept intact. At the close of two years, the percentage of healthy plants in the shaded and cleared plot, respectively, was 34 and 59, the percentage of the surviving plants which had not died back was 10 and 25, while the average height of the plants was 5" and 12·4", respectively. The fact that the ground was worked and dead leaves removed for two years in succession was responsible for the results in the shade being considerably better than usual, but there can be no question as to the marked superiority of the open plot. In the cleared plot also, taking only the 4 best plants (which would be sufficient to stock the area of the plot, *viz.*, 18′ × 3′), their average height was 20½" which fairly closely approaches the ideal seedling development for the locality which was noted at the beginning of this paper *viz.*, 26".

Plate IV, fig. 1 shows the shade plot and Plate IV, fig. 2 the cleared plot at the close of this experiment in July 1915.

The conditions necessary for the successful growth of *sal* seedlings, therefore, may be said to have been determined as follows :—

(1) a well aerated seed-bed free of raw humus;

(2) full overhead light;

(3) light side-shade sufficient to prevent damage from frost and to keep the soil moist in the dry season.

As regards the identity of the injurious soil factor alluded to, all the facts hitherto ascertained indicate that it can be rendered

innocuous by sufficiently good soil-aeration and, for the present, it may be conveniently indicated by the general term bad soil-aeration. It is not at present possible to define it more exactly or to indicate the precise way in which good aeration renders it innocuous. One thing, however, is clear, *viz.*, that the injurious action is not due merely to an excess of water in the neighbourhood of the roots. This has been praved by a water-culture experiment carried out at Dehra Dun during last rains, in which the injurious factor was found to be practically inoperative. In this case, after 75—78 days in the water-culture, only 8 per cent. of the *sal* seedlings died and the average length of healthy root in the surviving plants was 5·9." A simultaneous culture in badly aerated soil for a period of only 67 days resulted in 93 per cent. of deaths and an average length of healthy root of 1" only. Plate V, fig. 1 shows the appearance of the seedlings after 75—78 days in the water-culture and Plate V, fig. 2 shows the root-development of 6 typical specimens.

Other factors possibly concerned are the lack of sufficient oxygen for root respiration and the production and accumulation in injurious quantities in the soil of one or more substances which are directly poisonous to the roots. Further work is required to determine the relative importance of these factors. In the meantime, however, it is interesting to note that Mr. C. M. Hutchinson, Imperial Agricultural Bacteriologist at Pusa, who kindly examined samples of the soils from the corked pots mentioned in the above experiments, has found bacterio-toxins in all of them. These toxins are said to be capable of inhibiting nitrification and of directly injuring seedlings.

In conclusion, it may be noted that the accurate identification of this soil-factor is important for Indian Forestry, not only on account of its effect on seedlings, but also because of its possible action on older trees. There is reason to believe, for example, that, in the wet *sal* forests of Assam and the Bengal Duars which enjoy an annual rainfall of some 200", the intensity of this injurious factor progressively increases with the age of the forest and materially affects the health of the older trees—possibly preparing the way for the attacks of injurious soil fungi and other parasites.

Fig. 1.

Forest shade plot V. Photograph taken 20th July 1915. Note the appearance of the 2-years-old seedlings surviving in the plot.

Fig. 2.

Forest Plot IV. An area 60 ft. in diameter was here clear-felled in May, 1913. The photograph was taken on 20th July 1915. Note the vigorous 2-years-old seedlings surviving in the plot.

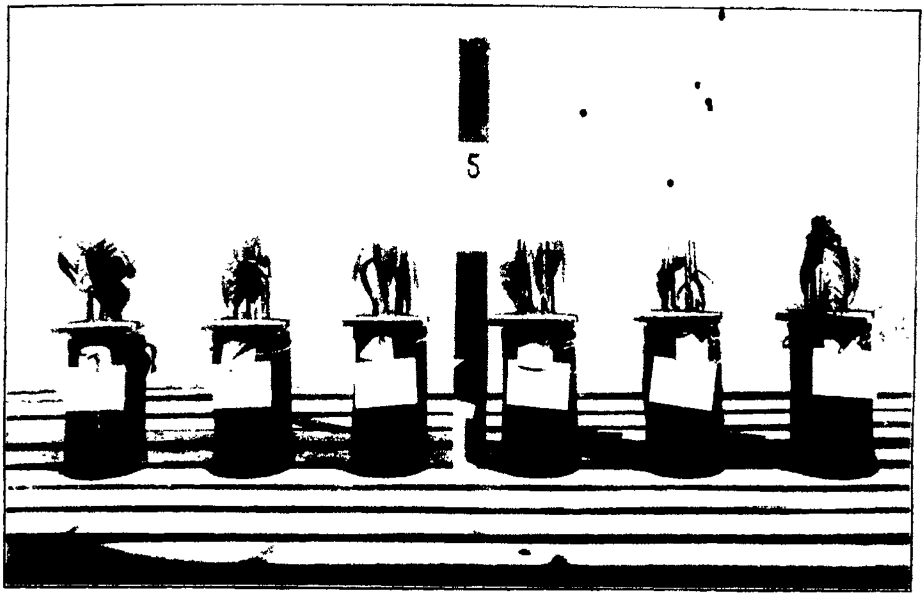


Fig. 1.

Photograph taken 27th October 1915, showing 12 *Sal* seedlings which have been grown continuously in a water-culture solution for a period of 75 (in the case of four plants on the right) to 78 days (in the case of 8 plants on the left.)

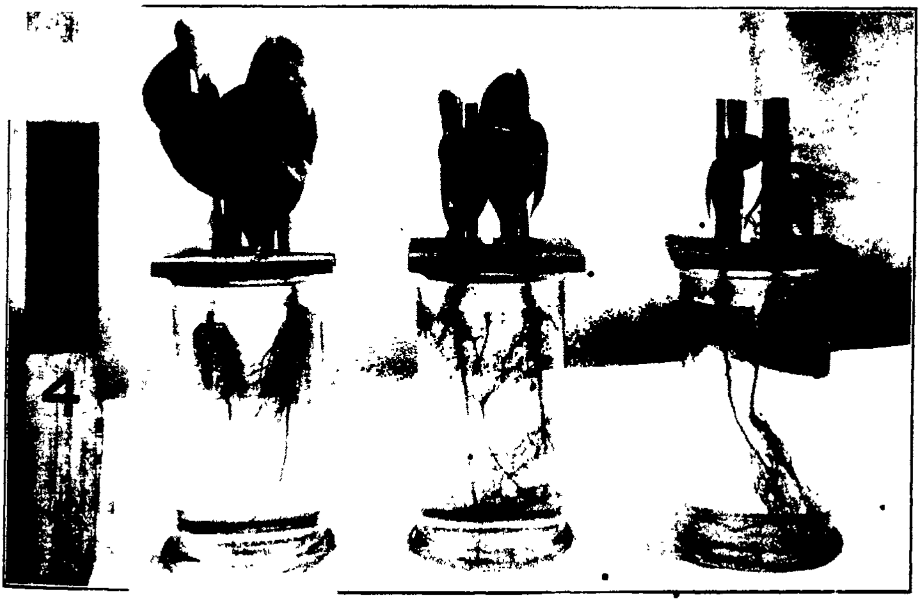


Fig. 2.

Photograph taken 27th October 1915, showing the root-development of 6 *Sal* seedlings which have been grown continuously in a water-culture solution for 78 days, in the case of the 4 plants on the left, and for 75 days, in the case of the 2 smaller plants on the right.

THE RE-ALIGNMENT OF AGRICULTURAL HOLDINGS.

BY

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MOST countries with a large peasant population have found it necessary at some time or other to introduce legislation for the re-alignment of holdings to enable the available land to be more economically and efficiently cultivated. The subject has been ventilated from time to time in India but little has been done. It is true that the waste of irrigation water, caused by the present haphazard system, has often been insisted upon, and in the Punjab care has been taken to avoid this on the great new canal systems. Near Poona in the Bombay Presidency the Irrigation Department is now engaged on the squaring up of fields and the drafting of rules to enable greater economy of distribution to be effected on the small, but important, canal systems which are chiefly used for sugarcane. Generally speaking, however, the advocate of re-striping is looked upon as an impatient idealist whose methodical soul is vexed by the present irregular field boundaries.

It has to be admitted that there are great practical obstacles in the way. The present land tenure system of the United Provinces, especially in that portion which comes under the Agra Tenancy Act, makes it exceedingly difficult to alter field boundaries without infringing vested interests. An occupancy tenant possesses cultivating rights in a definite plot of land, which may be only a fraction of an acre in area, and not only can he not be dispossessed, but there is no legal way in which his occupancy rights can be purchased from

him except in those cases where land is acquired by Government. Nor is the ownership of land any more simple. Many villages are now owned by a number of petty zamindars whose land is scattered in different parts of the village, so that any arrangement for general betterment by consent is practically impossible. It is obvious, therefore, that progress in this direction could only be made with the aid of special legislation.

The natural obstacles being what they are it is essential to show that the economic benefits to be derived from re-striping are such as to justify the necessary measures. It may be noted, however, in passing, that the present situation is largely the result of legislation undertaken within the last fifty years. The whole of the Indian land tenure system is based on the assumption that all land is the property of the state. The present system of landlords, with the private ownership of land, is a comparatively recent creation following on British rule and based on English analogies. Introduced as it was to save the agriculture of the country from the evils of the system of farming out blocks of land to contractors for the collection of revenue, it has largely justified itself, and the same may be said to be true of the tenancy laws which were introduced to further protect the tenant. It is only natural, however, that legislation introduced to meet pressing political needs should fail to take account of the effect on subsequent economic development. Should it be found that the tenancy laws in their present form are creating a new evil by checking economic development a strong case for their further modification would exist.

The present scattering of parts of a holding in different parts of the village, which is perhaps one of the first things which strikes the student accustomed to the compact farms of the west, is largely a result of the existing scheme of village life. Instead of each tenant residing on his holding it is usual to find all living in a central *basti*, even if it involves journeys of two or three miles for himself and his cattle. The system is wasteful of labour and cattle power and also of manure but has certain advantages. It doubtless arose when the mutual protection of life and property was more essential than at present, but it is unlikely that the present social organization

will be greatly disturbed in the near future, though signs are not wanting of a steady tendency to form smaller sub-villages nearer to the fields. While it is doubtless of some advantage to the individual tenant to have his holding spread over the different classes of available land, the system suffers from the disadvantage that there is less encouragement for a cultivator to concentrate attention on handling one class of soil adequately. Were this, however, the only point to be gained by the re-alignment of holdings one would be inclined to allow it to come about gradually as the result of changing social and economic conditions.

The greatest disadvantage of the present system, however, is that it prevents any tract of land from being treated as a whole and general measures taken for its improvement. The greatest limiting factor in Indian agriculture is undoubtedly the water-supply, and it is extremely difficult to take steps to improve existing conditions with the present system of holdings. In canal-irrigated tracts the area irrigated is almost invariably much less than the area commanded by the canal. The main great irrigation sources of the Province have already been harnessed and further development must either take the form of better economy in the use of the existing sources or the exploitation of schemes involving greater working cost and often higher capital expenditure and, therefore, more expensive water. It is commonly accepted that, from the great canals only about one-third of the water reaches the field, and that while some margin exists for the reduction of the amount of water actually applied the main losses occur in the canal channels and in the subsidiary village channels which share the loss fairly equally. The prevention of loss by seepage from canal channels is beyond the scope of the present paper, but it may be noted in passing that any radical measures in this direction must involve additional capital outlay and, therefore, either a rise in the canal rates or better utilization of the water. The loss in village channels is to a great extent avoidable. At present the village water courses follow field boundaries and are consequently unnecessarily long and tortuous and often undesirably aligned as regards levels. While steady improvement in this direction is being effected

through the influence of irrigation officers many of the worst cases cannot be touched. Nor is the situation appreciably better in tracts which depend on wells for their irrigation. The channels from these also are often unnecessarily long and devious, and the scattered ownership of the small fields often puts obstacles in the way of the construction of much needed wells. With more compact and better aligned holdings there would be a greater incentive to the construction of larger wells (or of tube wells) enabling a larger area to be irrigated with less labour. Recent experiments seem to indicate that there is a great future for the employment of oil engines and pumps both on the best masonry wells and on tube wells, but with holdings in their present form, economical distribution of the water is difficult and in many cases so many small interests are involved that it would be difficult to meet them all.

It would be easy to cite many other instances of indirect disadvantages for which irregular field boundaries are responsible, *e.g.*, the absence of decent roadways to give access to the fields, difficulties as regards threshing floors and the carriage of produce and manure, but it is sufficient to say here that they all share one feature, *viz.*, that, except in the case of works undertaken by Government, armed with the powers of the Land Acquisition Act, progress is almost impossible under present conditions.

It is now proposed to consider the effect of present conditions on the actual cultivation of the land. The maintenance of correct levels in a field during all processes of cultivation is recognized in most countries as one of the essentials of good farming. In the Gangetic plain, with an exceptionally easily worked soil, the results of carelessness in this direction are not so readily noticeable, but, on the other hand, the nature of the climate—characterized by heavy falls of rain confined to certain periods of the year and that (in the case of cold weather crops) not the growing season—makes the conservation of rain-water and its correct distribution on the land of vital importance. It being almost impossible to correctly plough a small irregular field, it is not surprising that most cultivators' fields show bad patches which are frequently due to nothing more than faulty levels. The lower patches are water-logged during

the monsoon while the higher patches dry out too quickly in the cold weather. Even the best cultivators' fields are frequently saucer-shaped, with the result that there is water-logging in the centre and consequently a poor crop. When any form of iron plough is used to improve the general cultivation, the difficulties are accentuated as the deeper and more thorough the cultivation, the greater the necessity for the maintenance of correct levels. Simple as it may seem, there are few agricultural officers who have not been confronted with this cause of loss of yield at some time or another. The explanation as to why even comparatively slight and temporary local water-logging causes serious loss is probably to be found in the fact that successful cultivation in the plains of India largely depends on the maintenance of a suitable environment for nitrogen-fixing and nitrifying organisms during the monsoon period. Local water-logging during the monsoon, producing temporarily anaerobic conditions, causes a loss of available nitrogen and hence a diminished crop. The experiments carried out by Mr. and Mrs. Howard at Pusa show that not only does the wheat crop on water-logged land yield far less than on properly drained land, but that the result can be partially remedied—but at additional cost—by the application of nitrates. Generally it may be said that the present small and irregular fields common in many parts of this province seriously militate against the adequate conservation of soil moisture and the maintenance of fertility and, therefore, cause direct loss of produce. Further, they discourage the introduction of the more expensive improved ploughs and cultivating implements as it is difficult to work these to advantage in small irregular fields, whereas if the fields were decently aligned there is reason to believe that joint ownership of such implements would be practicable.

In no direction, however, is the need for the re-striping of holdings more clearly seen than in the problems of checking erosion and effecting adequate drainage. The question has been fully dealt with by Howard[1] so that it is sufficient here to deal with its main aspects only. We are so accustomed to think of the plains of India as flat

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[1] Howard, A. Soil Erosion and Surface Drainage. *Bulletin No. 53 of the Agricultural Research Institute, Pusa.*

that we are apt to overlook irregularities which, small as they are compared to the hill systems of other countries, are sufficient to be of a great importance in a country of heavy rainfall. As is pointed out by Howard comparatively gentle slopes are sufficient to allow large quantities of the finer particles to be removed from the higher lands to the lower with the result that the physical texture of both deteriorates. The high lands are annually denuded of their finer particles and the fertility and moisture-retaining capacity adversely affected. The low lands, constantly receiving the run-off from the high, are annually receiving unneeded additions of fine silt thus becoming heavier and less workable and in addition receive an excess of water preventing adequate cultivation in the rains and causing a direct loss of fertility. Figures are published in the Cawnpore Farm Report for 1915 which show that the introduction of suitable catch drains on an area of this type has made it possible to raise a normal good crop of wheat on land that a few years ago *had to be thrown* out of wheat cultivation on account of the water-logging that took place in the rains. On a larger scale the recently opened Kalianpur Farm provides an example of a piece of land, previously only barely culturable, which has been converted into a good farm by proper terracing and correct laying out; the capital value of the land, as judged by its yielding capacity, has trebled in about 5 years. Operations of this nature, however, require control over a considerable area. Given this control it would not be difficult, nor unduly expensive, after a proper survey to lay out most villages with proper drains and banks to stop erosion and prevent water-logging of the low areas, providing suitable roads, footpaths and proper irrigation channels. At Kalianpur indeed it was found possible to make the channels serve the double purpose of catch drains and irrigation channels. Under present conditions, however, it is impossible to carry out alterations of this kind unless the land is the property of Government or, in rare cases, of a single individual.

Finally, in the case of one crop at least, the present lay-out of the average village hampers economic development and prevents the cultivator from getting a fair price for his produce. There are

many tracts in this province where the grower would willingly sell his sugarcane to a factory at prices more favourable to the factory than obtainable in most cane-growing countries. But the small scattered holdings often make the transport problem insuperable although sufficient cane is already grown within a reasonable radius and more would be grown if a factory could be started. As a result the cane grown is not economically utilized and extension of cane cultivation is checked. In the writer's opinion the present tenancy system has a great deal to do with the comparative shyness of capital for enterprises of this nature.

It is realized that drastic legislation such as would be necessary to permit of the re-striping of holdings requires a strong public opinion to support it, and it is, therefore, suggested that the first step would be to acquire a few villages in different parts of the Province, carry out the necessary alteration, and re-let the new holdings to the original tenants as nearly as possible. An object lesson of this kind would soon convince the land-owning classes of the need for general measures and, pending legislation, some of them might be able to assist in carrying out partial schemes in their own property.

If any excuse is needed for bringing before a science congress a matter of purely economic importance it seems sufficient to say that the existing land tenure system of this Province imposes a limiting factor on the application of scientific method to agricultural improvement.

SCIENTIFIC METHODS IN AGRICULTURAL EXPERIMENTS.

BY

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HAVING had occasion recently to collate the results of a large number of field experiments conducted throughout India and having had some difficulty in drawing anything but vague general conclusions from them, it occurred to the writer that a plea for more scientific planning and execution of such experiments might not be out of place.

The Rothamsted experiments seem to have been taken perhaps too much as a model on which experiments in India should be planned rather than as supplying a basis of information to be utilized in devising experiments more particularly suited to Indian conditions.

The information provided by the Rothamsted experiments is of two kinds, relating, firstly, to the reaction of the Rothamsted soil, and of the crops grown there to different manurial applications, and, secondly, to the wider subject of field experiments generally.

Little need be said about the first of these aspects except as regards certain limitations to the direct application of the results to conditions other than those under which the experiments were tried.

These results have proved that the application of manures containing nitrogen and the elements found in plant ashes, in quantities of the order of magnitude in which these elements are removed in crops, has a marked influence direct or indirect on the production of crops.

They have shown also that by a continued application of a manure complete in all but one of the important ash elements, the productive capacity even of land that contains enormous reserves of that one element may, by the removal of the crops grown, be reduced, in a comparatively small number of years, to very much below normal. And they have shown how rapidly nitrogen may be accumulated by the growth of leguminous crops, provided that a moderate supply of these ash elements in a soluble condition is maintained.

But while a foundation for local investigations has thus been provided, in the principle of supplementing the weakest links in the chain of chemical elements on which fertility depends, by a supply of the deficient elements in a soluble form, no attempt has been made at Rothamsted even to illustrate by local example, the solution of what must always be a local economic problem—that of adapting agricultural practice so as economically to extract from the insoluble reserves in the soil, and maintain in a relatively available form, sufficient proportions of the principal elements required by crops.

The cropping of Rothamsted has been purposely exhaustive, and manures have been freely supplied from outside; no attempt has been made to make the most economical use of the reserves of plant food existing in the soil, the full utilization of which must always be, in greater or less degree, an object of agricultural practice.

The importance of this point is shown by the rapidity with which the available potash was exhausted at Rothamsted, on a plot which received a manure containing all the other essential elements of plant food; and this, although the soil when completely broken down by hydrofluoric acid, was found to contain over 2½ per cent. of potash. Mr. Taylor at Sabour has similarly found over 6 per cent. of potash (over 8 tons, per inch depth, per acre) in a soil from Ranchi—where, nevertheless, ashes form one of the chief manures.

Now India is a poor country, and cultivators cannot afford to import over the long distances into the interior, any great quantity of heavy manures; or to use, as manure, what might otherwise be

These results, depending chiefly on avoidable or unavoidable physical differences between the plots, are, of course, not quantitatively applicable to conditions other than those under which they were obtained. But the principle is of greater importance in proportion as the effective control of the experimental area is less, and is probably therefore more important under the conditions obtaining on most experimental farms in India than it is at Rothamsted where minor variations in the soil are less accentuated by extremes of rainfall or drought, and where the work was laid out on land carefully selected for uniformity in the light of a previous known history.

Yet on how many farms in India are even the five plots recommended by Hall and Mercer considered necessary for each comparison; and, where only two, or at most three plots are used, what results worth having can be obtained in the limited number of years over which a consistent policy can usually be maintained?

Acting on the principles that have been emphasized, the writer made an attempt during the last monsoon to throw some light on the manurial problems of Chota Nagpur, where immediate results were required to supply an existing organization with material for propaganda.

The conditions were unfavourable, the farm at Ranchi was started in May 1915, the land being then uncultivated. The best land that could be selected was not by any means uniform, as it was intersected by low terraces and was being carted over by building contractors. Inequalities had to be ignored; carting was stopped; and six acres were divided by low ridges at right angles into 60 plots, each 40 links wide by 250 long.

Analysis of the soil having shown a marked deficiency of lime and phosphoric acid, and only a trace of sulphur, it was decided to devote the whole 60 plots to quantitative tests of the effect on groundnuts of lime, sulphur, and bonemeal—the latter being used only because raw mineral phosphates were unobtainable owing to freight difficulties. The general scheme was based on the division of the area into series of plots for testing the different manures,

alone and in combination; test and control plots being alternated throughout. In comparing the results, the weight of produce of each variant plot was compared with the sum of the weights from the control plots on either side of it.

The details of the results, which will be published in the Farm report, are of no particular interest, except in the case of sulphur, to which reference has already been made.

The effect of sulphur was quite phenomenal and would have needed no duplication of plots for its detection, even when only 10 lb. per acre (costing 12 annas) was applied. Slaked lime, in all quantities up to 5,600 lb. per acre, was also markedly beneficial.

But the general character of the results is best illustrated by those given by bonemeal. This manure gave a markedly increased yield in each of 5 plots to which it was applied without lime, but when applied in addition to 4,000 lb. of slaked lime per acre it gave a relatively much smaller increase in 6 out of 7 plots, and this increase had again to be discounted by a decrease of 20 per cent. on the seventh plot—a discrepancy clearly due to 'experimental error,' of the importance of which in this case it gives some idea. If the number of plots had been much smaller, either the significance of the results might have been overlooked, or the discrepancies might have led to their rejection as inconclusive. As it is, conclusions have been drawn which, while showing weak points in the original plan of the experiments, have both enabled immediate recommendations to be made to cultivators, and have provided a solid basis on which to plan a new set of experiments for next year.

THE IMPORTANCE OF SOIL VENTILATION ON THE ALLUVIUM.

BY

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I. Introduction.

The dominant factor in the internal economy of the Indian Empire is the monsoon. The well-being of the people, the commerce of the country and the revenue collected by Government all depend on the amount and distribution of the summer rainfall. It is not surprising, therefore, to find that the attention of the agricultural investigator in India tends to be concentrated on questions relating to the supply of water to crops. At the same time, the other factors on which yield depends are apt to be obscured and crop-production comes to be regarded almost entirely as a question of water-supply. After ten years' observation of the crops grown on the Indo-Gangetic alluvium, during which a good deal of first-hand experience in agriculture has been obtained at Pusa in Bihar, at Lyallpur in the Punjab, and at Quetta in Baluchistan, the conclusion has been reached that a full supply of air in the soil is quite as important as a sufficiency of water. While air is a necessary raw material for the roots of plants wherever they may be grown, efficient soil ventilation is found in practice to be particularly difficult on alluvial soils like those met with over large areas of the plains of India. Alluvial soils, like those of the valleys of the Ganges and Indus, pack very readily and always run together on the surface after heavy rain forming a well-defined crust, well-known to any cultivator as the *papri*. Two chief factors are responsible for the ease with which

these soils form surface crusts after light showers and lose their porosity altogether after long continued rain. In the first place, the soil particles are small in size and exhibit no very great range in diameter and, in the second place, much of the rain comes in heavy continuous torrents quite unlike anything experienced in temperate regions.

Defective aeration of the soil, besides interfering with the respiration of the active cells of the root and of the soil bacteria, exercises a profound influence on the development of the root-system itself.* Where the subsoil is wet and consolidated and gaseous interchange between the soil and the atmosphere has been checked, crops are found to develop superficial roots only and are then particularly liable to the harmful effects of drought. To withstand any shortage of moisture, to make the most of the brief growing season and to ripen the crop before the onset of the hot weather, the root-system of all *rabi* crops must be deep. In the *kharif*, long continued and heavy rain, by destroying the porosity of the soil and by thus interfering with the air supply to the roots and to the soil organisms, leads to a wilted, poverty-stricken condition of the crops and to a diminished yield. Such examples of damage to monsoon crops, caused by excessive rain interfering with aeration, were common in many parts of the United Provinces during the later phases of the 1915 monsoon.

II. Some Examples of Soil Ventilation.

Among the numerous instances observed of the effect of improved soil-ventilation on the growth of crops it will be sufficient to quote a few examples.

1. *The yellowing of peach trees.* As the summer progresses at Quetta, the foliage of many of the peach trees alters in colour and changes first to light-green and finally to yellow. Premature leaf-fall then takes place and, by the end of August, many of the branches are almost bare of leaves. In addition to the yellowing of the foliage, two other symptoms manifest themselves. The wood gives off large quantities of gum and the ripening fruit is deficient in flavour. Peach trees affected in this way die out in two or three

years, the process taking place in stages by the death of one or two large branches at a time. Investigation of the trouble showed that this unhealthy condition was not caused by want of available nitrogen in the soil and was not a real disease of the nature of the "peach yellows" of the United States. Buds taken from affected trees produced healthy plants and therefore the unhealthy condition was not transmitted in propagation. Yellowing was found to be reproduced at will, either by deep-planting or by over-irrigation. Any effective method of soil-aeration was found to transform affected trees into a healthy, vigorous condition in a single season. Yellowing and the premature death of the peach trees at Quetta was therefore found to be the result of defective aeration of the soil caused by excessive surface-flooding under arid conditions. The affected trees naturally carried a load of parasites such as scale insects and a certain number of fungi but with the resumption of healthy growth these pests gradually disappeared.

2. *Soil-aeration and green-manuring.* The provision of some cheap form of organic matter is one of the great needs of Indian agriculture at the present time. As is well known, the amount of manure available is small due to the fact that most of the cow-dung is burnt as fuel and almost all the *bhusa* is used for feeding cattle. As a rule, Indian soils are deficient in organic matter and the yield is limited by this factor. One theoretical method of making up the deficiency is by green-manuring but, in practice, difficulties arise. A considerable amount of attention has been paid to this subject in the Botanical Area at Pusa and the conditions necessary for the success of this operation have now been worked out. If a crop like *sanai* (*Crotalaria juncea*) is raised on the early monsoon rains and ploughed in during July, it is found that the texture of the soil is improved and, in a few cases on light land, the succeeding *rabi* crop benefits enormously by the addition of the organic matter left by the decay of the green crop. In the majority of Bihar soils, however, these results are not obtained and the *rabi* crops following green-manure are much worse than those raised on ordinary fallowed land. As a rule, green-manuring leads to a diminished *rabi* crop although the process results in the addition of a considerable

amount of organic matter to the soil. After some years' experiment, it was found that the factors on which success in green-manuring depends are connected with the air-supply in the soil. If the land is surface-drained and, if provision is made so that each field is protected from the run-off of other areas by a suitable arrangement of trenches, the effect of a green-manure crop is materially increased. If, in addition, the land is subsoiled to a depth of twelve inches before the *rabi* crops are sown, still better results are obtained. When broken tiles (*thikra*), at the rate of about 50 tons to the acre, are mixed with the upper six inches of soil, the results are exceedingly striking and a maximum crop can easily be obtained by green-manuring alone.

The simplest explanation of these results appears to be connected with the part played by air in the soil. The soil is usually regarded as a mass of small particles, arranged in various ways according to the degree of consolidation, with free spaces between these bodies known collectively as the pore-space. Surrounding the solid particles are films of water of various thicknesses while the rest of the pore-space is taken up by the soil-air. The proportion of the pore-space filled by water and air naturally varies with the general wetness or dryness of the soil. The closeness of packing of the solid particles varies greatly, after a crop is sown, as a result of consolidation by irrigation water or rain. In the water films round the particles, there is intense biological activity. Numerous bacteria are rapidly reproducing themselves while the root-hairs of the crop are competing with these soil organisms for water and inorganic food materials. All the protoplasm of these organisms is actively respiring and, in consequence, there is, in the water films round the particles, a keen struggle for oxygen and a great development of carbon dioxide. Under such circumstances, it is easy to understand how it is that analyses of the general soil-air often show a high proportion of carbon dioxide and a comparatively low percentage of oxygen. We must now consider what is likely to happen if this normal struggle for dissolved oxygen in the soil between the roots of the plant and the soil organisms is complicated by the sudden addition of a green crop like *sanai*. In the first place, the growth

of the green crop itself will naturally lead to a considerable pollution of the soil atmosphere by carbon dioxide. As soon as it is ploughed in, decay begins and an enormous quantity of oxygen is used up in the process which is by no means complete when the sowing time of a *rabi* crop comes round. The partly decayed organic matter adds a new competitor in the struggle for oxygen. It is easy to understand how the remains of the green crop might easily use up the oxygen in the pore-spaces and load the soil atmosphere with carbon dioxide to such an extent as to poison the air dissolved in the water films. Oxygen starvation and carbonic acid poisoning would affect the plant and growth would be checked. If we improve the aeration by drainage and by adding *thikra,* the decay of the green crop would be hastened and the air-supply of the soil during the succeeding *rabi* crop would be increased to such an extent that oxygen would no longer be a limiting factor.

The nodules of leguminous plants. The copious aeration of the soil in which leguminous crops are grown is perhaps more important than in any other class of cultivated plants. These crops require nitrogen for their nodules as well as oxygen for the respiration of the roots themselves. Once these facts are realized, it is easy to understand the distribution of leguminous crops in India and the agricultural processes in vogue in their cultivation.

The distribution of the gram crop closely follows the occurrence of well-aerated soils. It is only grown under irrigation where the soil is particularly porous or where there is a well-drained and well-aerated subsoil as occurs in many parts of the Bombay Presidency. If an attempt is made to grow this plant in stiff, heavy land, such as the low-lying loams of North Bihar, the result is disastrous. The plants only form roots near the surface and hardly any nodules are produced. The yield is scarcely more than the seed sown. Similar results are obtained under canal irrigation in the stiff loams in the Canal Colonies of the Punjab and other tracts of India. Heavy rains during the cold weather often destroy this crop simply by forming impervious surface-crusts and cutting off the supply of air to the nodules and roots.

In the growth of *rahar* (*Cajanus indicus*) in those tracts of India where the monsoon rainfall is heavy, the best results are obtained by digging the soil between the plants after the monsoon. Heavy rains consolidate the fine alluvium and the digging is necessary to restore aeration. In a similar manner, the Java indigo crop will only form seed in Bihar when the copious aeration of the roots is provided for. The slightest interference with the air-supply soon makes itself manifest by leaf-fall and by the shedding of flowers without setting seed.

III. The Maturation of Crops.

Besides its influence on the actual growth of crops, the provision of an abundant air-supply appears to be bound up with the ripening processes and with the development of quality.

In the case of the wheat crop, the best grown samples are always produced in tracts like the Meerut Division of the United Provinces or on the black soils of Central India, where the soils are naturally highly porous. In Bihar, Oudh, and in parts of the Punjab, where the natural porosity is not so great, the grain is always much thinner in appearance particularly in years when the rainfall is heavy during the ripening period. Unless the wheat roots get plenty of air during the process of maturation, the sample is always relatively poor.

Anyone who has studied the peach tree and has attempted to grow this fruit to perfection must have been impressed by the difference in quality of the same variety when the peach is grown on soils a little heavier than the normal. As is well-known, the peach thrives best on open soils and is particularly sensitive to any form of water-logging. Some years ago, the Botanical Section at Pusa achieved a local reputation on account of the excellence of the peaches grown there. The varieties were only country kinds but they were grown on high land containing a fair proportion of broken tiles (*thikra*). The soil was thus highly porous and the roots obtained abundance of air. The quality of the fruit was excellent compared with the produce of similar trees on land close by a little heavier in texture which contained no *thikra*.

In the growth of vegetables and flowers, some of the soils of Lucknow are famous. The best produce is raised under irrigation on the highly-manured sands near the banks of the Gumti. The soils in themselves are poor but, when properly manured and watered, their porosity is so great that surface-flooding causes little or no damage to its texture. The roots of the vegetables and flowers thus obtain abundant air and grow to perfection. The vegetables have excellent taste while the flowers easily form a quantity of good seed. Here again the development of quality seems to be closely associated with soil-aeration.

A similar result is seen in tobacco growing in Bihar. The best tobacco is grown on high, light lands which have been manured with indigo *seeth*. The *mahajans* pay more for such produce and several of the indigo factories have a reputation for their tobacco. *Seeth* is undoubtedly a most efficient aerating agent and all the experience obtained at Pusa in the growth of the tobacco crop points to the supreme importance of soil-aeration in the ripening of this crop. Once more, quality appears to be closely bound up with the ventilation of the soil which again appears to be of supreme importance in the process of maturation.

THE DYEING VALUES OF SOME INDIGENOUS DYE-STUFFS.*

BY

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I.

NATURAL dye-stuffs are perhaps not as bad as they have come to be regarded since their displacement by coal-tar colours. India boasted of a comparatively well developed art of dyeing in the earliest stages of the historic period. The ancient Indian dyer could dye some very good colours with the help of colouring matters derived from the natural and mineral kingdoms. Some of these colours were fast in every sense of the word and answered all the requirements of the people for whom they were intended. This points to the possibility of valuable colouring matters lying unknown or forgotten in the forests and jungles of this country.

A large number of woods containing red and yellow colouring matters are still used even in Europe but all these are obtained from America. There are undoubtedly similar woods in this country but so far no systematic investigation seems to have been made.

If America can find a market for so many dye-stuff extracts made from woods and other natural products, surely we with our vast, varied, and plentiful natural resources ought to have little

* Of the two papers printed here only the second was contributed to the Indian Science Congress. The first was published by the Board of Industries, United Provinces, before the Congress was held. It has, however, been reprinted here as the second paper is in continuation of it.

difficulty in finding out and placing on the market similar products.

This question is of special importance at the present moment. The stoppage of the supply of German dye-stuffs has caused grave inconvenience in all colour-using industries. If Indian dye-stuffs had not been entirely discarded the distress would not have been so acute. At least some part of the world's requirements would have been met by the dye-stuffs indigenous to this country.

Colouring matters are widely disseminated in the vegetable kingdom. Some one has said that any one who wishes to spin, dye and weave his own raw material at his own fireside need not go far afield for his colouring matters.

Such is indeed the case in a great many places where cottage industries still flourish. In Donegal, famous for its homespun tweeds, the colouring matters used are still mostly derived from lichens and roots. The colouring matters of Donegal possess great fastness and beauty and their methods of application are alike novel and interesting.

I visited Donegal in December 1909 and submitted to the Secretary of State for India a report on the subject of the cottage industries of the congested districts of Ireland. I have alluded in this report to the processes of dyeing used in Donegal.

The following investigation into the dyeing values of certain natural colouring matters still used by native dyers was undertaken under the orders of the Director of Industries, United Provinces.

The colouring matters were tried on wool and cotton by some of the more important methods of modern dyeing.

The methods employed were as follows :—

A. On Wool.

(*a*) Dyed in an infusion of the colouring matter without the addition of any chemical or assistant to the dye-bath.

(*b*) Dyed in an infusion of the colouring matter with the addition of 4 per cent. acetic acid.

(*c*) Dyed as in (*b*) and after-treated in the same bath with 2 per cent. potassium bichromate.

(*d*) Dyed in an infusion of the colouring matter on wool which had been previously mordanted with bichrome and oxalic acid.

(*e*) Dyed in an infusion of the colouring matter on wool which had been previously mordanted with aluminium sulphate and tartar.

B. ON COTTON.

The cotton was steeped overnight in a decoction of myrabolans, next morning it was taken out, squeezed and without washing worked in fresh baths containing the following :—

(*a*) Tartar emetic.

(*b*) Stannous chloride.

(*c*) Alum.

(*d*) Ferrous sulphate.

Generally speaking all the dye-stuffs described hereafter gave the most brilliant results on stannous chloride; tartar emetic and alum coming after that. Ferrous sulphate, as might be expected, dyed grey to black shades.

The inquiry has so far been prosecuted in regard to the following colouring matters :—

(1) HARSINGHAR. (*Nyctanthes Arbor-tristis*).

The flowers of this tree contain a beautiful yellow colouring matter. The tree is found in abundance in the United Provinces and when in bloom yields large numbers of flowers which generally open at night and fall to the ground in the morning. The flowers are collected, dried, and afterwards sold to dyers.

The colouring matter contained in the flowers is soluble in water, also in alcohol. An extract can therefore be easily made.

Harsinghar gives brilliant yellow shades with all mordants on wool. On wool mordanted with bichrome and oxalic acid previous to dyeing a beautiful brown is obtained. The dyeings on wool possess good fastness to milling with soap and soda.

(2) TUN. (*Cedrela Toona*).

This tree is said to occur largely in the sub-Himalayan forests. The colouring matter is contained in the flowers which are dried and sold. The principal constituent of the flowers is a yellow dye.

Tun dyes the best shade on wool in conjunction with mordant A(*d*). The dyeings on wool are, however, not very fast to milling with soap and soda.

(3) Tesu or Dhak. (*Butea frondosa*).

This tree is found in abundance all over the United Provinces. The dye extracted from the flowers is still largely used by villagers for sprinkling on their persons as a mark of festivity at Holi festival, about which time the tree is in full bloom. The dried flowers are, however, available throughout the year. The flowers contain a yellow colouring matter.

Tesu dyes on wool shades varying from brown to dull crimson according to the mordant used.

The dyeings are fairly fast to milling.

(4) Haldi or Turmeric. (*Curcuma longa*).

The plant which yields *haldi* is grown all over the United Provinces. *Haldi* is a dried rhizome or tuber and is a well-known constituent of curry powder. It is largely used as a spice and can be had in any quantity in the bazar. It contains a brilliant yellow colouring matter which however possesses the serious drawback of being changed into red by soap or by alkalis.

The colouring principle of *haldi* is called *curcumin*; it is sparingly soluble in cold water, more freely in hot water, and completely in alcohol. The use of turmeric paper in analytical chemistry is well known. Paper saturated with a solution of turmeric is changed to a reddish brown colour by alkalis; while its reaction with boric acid is still more characteristic. Turmeric paper on being moistened with boric acid and dried becomes brownish red which colour is changed to blue or green by caustic soda.

On wool the best shade is obtained on chrome mordant A(*d*). The fastness of the dyeings on wool is fair.

(5) Arusa. (*Adhatoda vasica*).

The leaves of this plant yield a yellow colour. *Arusa* is an ever-green plant and is found in the United Provinces. The

colouring matter in *arusa* is soluble in water and also in alcohol. The leaves contain a large amount of chlorophyl which is extracted along with the yellow colouring matter. The chlorophyl considerably dulls the dyeings obtained with *arusa*. The yellow dye was separated by adding water to an alcoholic extract of the leaves. The chlorophyl was thereby thrown out of solution and the yellow colouring principle was obtained in the filtrate. This gave much better results in dyeing. On wool the best shade is obtained on chrome mordant A(*d*). The fastness of the dyeings on wool is fair.

(6) NASPAL OR POMEGRANATE RIND. (*Punica granatum*).

This plant is well known for its fruit. The rind of the fruit contains a tanning substance and also a yellow colouring matter, the latter in much smaller quantity than the former.

Pomegranate rind dyes very good shades varying from yellow to full brown on wool. All these possess very good fastness to milling.

(7) JANGLI NIL OR WILD INDIGO. (*Tephrosia purpurea*).

This is a small woody annual occurring in abundance in the United Provinces It does not contain any substance yielding indigo and its name " Jangli Nil " is probably due to its similarity to the indigo plant.

Clarke and Banerjee have examined the constituents of the leaves of this plant. They found in it a colouring principle allied to quercetin or quercitrin (vide *Trans. Chem. Soc.* 1910, V. 97). Owing to the difficulty of separating the yellow principle from the chlorophyl, efforts to obtain a pure yellow from *Tephrosia* have only been partly successful. The colouring matter is, however, of great value, as it yields dyeings which are comparatively fast to light, washing, and milling. The yellow principle was separated by extracting the dry leaves with alcohol, diluting the extract with water, and washing away the chlorophyl with petrol. The purified colouring matter gave excellent shades of yellow in conjunction with various mordants. On account of the abundance of the plant it may be worth while devising a suitable process for extracting

the yellow colouring principle. It would no doubt be very welcome wherever fustic and quercitron bark are still in use. A decoction of the leaves of *Tephrosia* dyes wool mostly dull brown shades in conjunction with the various mordants, the most brilliant shade being that on tin mordant. The dyeings, however, possess very good fastness to milling.

(8) SAFFLOWER OR KUSUM. (*Carthamus tinctorius*).

The dried flowers of safflower plant contain a colouring matter which before the introduction of coal-tar colours was highly prized all over the world. It produces on cotton beautiful shades of red varying from a full crimson to the most delicate pink. Safflower is rather an interesting material. It contains two distinct colouring matters, viz. (1) a yellow soluble in water which is by far the larger constituent, and (2) a red which only occurs in small quantities but is, nevertheless, the more valuable of the two. The separation of the two colouring matters is thus effected. The florets are macerated with water which extracts the yellow colouring matter. When the maceration is complete and yellow colouring matter is no longer extracted, the florets are mixed with a dilute solution of carbonate of soda (*sajji matti*) which extracts the pink colouring matter. The cotton is worked in this solution in the cold for a short time. The bath is then acidulated with tartaric acid and the cotton worked in it for a short while whereby the pink colour makes its appearance. Native dyers use lemon juice for acidulating. The action is similar to that of tartaric acid. Silk may be dyed similarly but safflower is not suited to dyeing wool.

Although the yellow colouring matter in safflower is generally regarded as useless, Hubner has shown that certain mummy cloths which he examined had been dyed with safflower yellow (vide *Journal of the Manchester School of Technology*, Vol. 3, page 359). He found that these cloths contained appreciable amounts of magnesium sulphate, and his experiments proved that an addition of magnesium sulphate helped cotton previously mordanted with iron to take up the yellow dye pretty well and the shades obtained were similar to those of the mummy cloths. The Egyptians

were therefore acquainted with the right way of using safflower yellow.

Strange as it may appear, safflower yellow does not dye cotton in conjunction with aluminium and tin mordants.

Wool, however, possesses affinity for the yellow colour and may be dyed direct.

(9) Majith. (*Rubia cordifolia*).

The root and twigs of this plant contain a dye-stuff identical with madder. *Majith* was largely used in this country before the advent of synthetic alizarine. Its cultivation has now, it seems, entirely gone out. It is at present greatly in demand all over India, but enquiries made so far have shown that it cannot be had in quantities large enough to meet the demand for it. It is undoubtedly one of the most valuable indigenous dye-stuffs. With its help red, maroon, and bordeaux shades of excellent fastness to light can be dyed on all fibres. It is the basis of a great many colours required by the calico-printers. The Farrukhabad calico-printers were at one time large users of this dye-stuff and would be glad to go back to it if supplies were forthcoming. *Majith*, as might be expected, dyes very fast shades on both wool and cotton. The best results on cotton are obtained by using the Turkey Red process.

(10) Cutch or Katha. (*Acacia catechu*).

The catechu tree is found in several parts of India. An extract made by boiling the wood in water is still largely used in dyeing. Catechu is exported to Europe for use in dyeing and tanning. Catechu may be applied to all fibres, though it is most largely used for dyeing cotton. The usual method of dyeing cotton consists in boiling the goods with an extract of catechu with the addition of copper sulphate, the weight of the copper salt being 10 per cent. of the weight of the colouring matter. The goods are squeezed, allowed to stand for a short time, and then boiled in a fresh hot bath containing 2 per cent. bichromate of potash, washed and dried. Catechu brown is one of the fastest colours known.

(11) PATANG OR SAPPAN WOOD.—(*Cæsalpinia sappan*).

This tree is said to grow abundantly in Cuttack and in Central India. It is a variety of the so-called Brazil wood which was once upon a time very largely used in dyeing in Europe. The colouring principle, *brazilein*, exists in a colourless condition in the freshly cut wood and is by oxidation converted into the true colouring matter *brazilein*. The wood is similar in its composition to logwood. The oxidation of the colouring matter is carried out by a process of "ageing" in exactly the same way as logwood.

Patang is a valuable colour-yielding material. It can be used for producing brilliant shades of red, crimson, and purple and is very suitable for calico-printing.

(12) LAC DYE.

This substance is of animal origin. It is the product of a small insect called *Coccus lacca* which lives on the twigs of certain trees such as *peepul* and *ber*. The incrustation produced by these insects on the twigs of the trees consists of (1) resinous matter, (2) colouring matter. The colouring matter is dissolved out by means of water or a weak alkali, the resin being left behind. The latter on melting and straining through canvas cloth constitutes *shellac*. The colouring matter is precipitated from its solution by means of alum and is afterwards pressed into cakes and sent out either for export or for sale locally.

Lac dye is manufactured largely in these provinces, though like other natural products it has lost much of its former importance Lac dye is dyed on wool, chiefly on tin mordant. It yields beautiful scarlet and crimson shades.

(13) INDIGO.

A description of this is perhaps unnecessary here. Its use and importance are too well known to be drawn attention to in this paper.

CONCLUSION.

In the scope of this report it has been only possible to allude briefly to the dyeing values and properties of the various colouring

matters examined. Exhaustive trials have already been made with all the above dye-stuffs in conjunction with various mordants on both wool and cotton. The dyeings obtained in each case have been tested for fastness to light, washing, and milling. All these samples are being shown at the Exhibition of German and Austrian Goods now open at the Upper India Chamber of Commerce, Cawnpore.

These samples have already attracted the attention of users of dye-stuffs who have visited the exhibition, and enquiries respecting them have been received from one or two places.

Surprising as it may appear at first sight, India's natural resources are capable of supplying dye-stuffs required for producing any colour.

The thirteen dye-stuffs described above will enable a clever dyer to produce almost any colour.

We have in the list dye-stuffs yielding yellows, olives, browns, khakis, slates, greys, blacks, reds, scarlets, pinks, and blues. Suitable combinations of these colours will give us almost any shade.

The fastness of many of these dye-stuffs is not so bad as one is often led to believe.

It must, however, be admitted that most of these dye-stuffs are not available to-day in large quantities and the prices are consequently prohibitive.

Haldi, *cutch*, safflower, lac dye, and indigo are commercial products and may be had in fairly large quantities. *Tun*, *tesu*, *arusa*, and *Tephrosia* occur wild and arrangements may easily be made for collecting them. *Harsinghar* and *naspal* are not exactly wild products and so their collection will necessitate special arrangements being made.

Majith and sappanwood are perhaps the most difficult to get at and so far as we have been able to gather their cultivation has practically gone out, but an enquiry into the matter is still proceeding.

A systematic study of the properties and methods of application of these dye-stuffs would no doubt bring to light many valuable facts which would make the dye-stuffs more popular with the

There is every likelihood of a great many more colouring matters being found in the forests of India but this would be a matter for the Forest Department to deal with.

II

The examination of indigenous dye materials has been continued in the Technical Laboratory at Cawnpore. A communication on this subject has already been made to Government. Since then some additional dye materials have been examined and the following is a brief account of their properties and methods of application in dyeing.

(1) Kachnar—(*Bauhinia racemosa*).

This is a shrub very common in these provinces. The bark yields a red dye which is largely associated with tannin. The dye is not very bright but nevertheless it may be employed for dyeing dull reds on cotton. It may be dyed on cotton without the help of any mordant. Cotton seems to have an affinity for it. Faster results are obtained on alumina or tin mordant. *Kachnar* bark is said to be used in Burma for obtaining a dull black colour on cotton. For this purpose the cotton is dyed direct in an infusion of the bark and is then worked in mud whereby the dull red colour is changed into a black (*vide* note by the Conservator of Forests, Eastern Circle, Burma, 1896). The bark can be had in any quantity, and may be of service to tent manufacturers who require a dull red colour for the inside of tents.

(2) Peepul—(*Ficus religiosa*).

The roots of this well-known plant were examined and found to contain a red dye which gives a good pink on cotton mordanted with alumina. The shade so obtained is fairly fast.

(3) Red Sanderswood—(*Pterocarpus santalinus*).

This is a small tree occurring in Southern India. The wood yields a valuable red dye. It was largely used in dyeing before the advent of synthetic colours. The dye principle is called santalin. It was prepared in the laboratory in an impure state from an ethereal

infusion of the wood. The crystals deposited. from the ethereal solution were further purified by washing them well with water, redissolving in alcohol, and precipitating with lead acetate. The precipitate was well washed with boiling alcohol and decomposed with sulphuric acid in the presence of alcohol, on removing the lead sulphate and concentrating the solution pure crystals of santalin were obtained. They melted at 103-105°C. (un-corr.)

Sanderswood dyes wool without any mordant. Very good shades of satisfactory fastness are obtained on cotton on tin and alumina mordants. The dye does not dissolve in water though it is freely soluble in alcohol, ether, and acetic acid.

(4) Roli or Kamela Powder—(*Mallotus philippinensis*).

This dye is obtained from a small tree found along the foot of the Himalayas and in Southern India. The fruits have red glands on the surface of the capsule and the powder is obtained by crushing or breaking up these glands. Kamela used to be largely employed for dyeing silk. It gives a beautiful yellow on silk mordanted with alumina. The shade obtained compares favourably with that dyed with chrysophenine. The dyeing must be done in an alkaline bath.

(5) Akhrot—(*Juglans regia*).

The bark yields a valuable brown dye. It is of special importance for wool at the present moment because it yields on this fibre a fast shade which may easily be modified to a khaki. A great many dye trials were made and as a result of these the following conclusions were arrived at :—

(*a*) The deepest shade is obtained by dyeing with an addition of 3 per cent. acetic acid to the dye-bath. The fastness to light is, however, poor in this case.

(*b*) Fairly full shades were obtained on chrome-oxalic acid mordant or by the after chroming process. Both these give dyeings of excellent fastness to light and milling. The poorest results both as regards

depth of shade and fastness to light and milling were obtained when the dyeing was carried out with an addition of 15 per cent. Glauber's salt to the dye-bath.

(6) Kathal. (*Artocarpus integrifolia*).

The wood yields a yellow dye which may be dyed on cotton on alumina mordant. The shades obtained are good and fast.

(7) Barberry. (*Raswat*).

The bark, roots, and stem of this plant are rich in a very good yellow dye. This plant is plentiful in the Kumaun Hills. The aqueous infusion of the bark and stem is used as a medicine for ophthalmia and is highly prized as such. The dye principle of barberry is berberine which is an alkaloid containing nitrogen. Berberine was prepared in a state of purity from barberry by adding alcohol to the aqueous extract whereby all foreign matter was precipitated. On concentrating the filtrate crystals of barberine were obtained which were purified by recrystallisation from water.

Raswat is used chiefly as a dye for silk. It was dyed on cotton mordanted with alumina but dull shades were obtained. This was perhaps due to the presence of chlorophyl in the preparation which came from Naini Tal.

(8) *Rhus cotinus.*

The wood of this plant yields a dye similar to young Fustic. On cotton mordanted with alumina an orange yellow colour was obtained; with tin an orange red was obtained. The dyeings are, however, not fast to alkalis and soap.

THE AQUATIC WEEDS OF THE GODAVARI AND PRAVARA CANALS OF THE BOMBAY PRESIDENCY—A PROBLEM IN APPLIED ECOLOGY.

BY

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In 1915 the author was invited to examine and report on the weed growth in the Godavari and Pravara Canals of the Bombay Presidency, since this growth had in some places become so great as seriously to impede the flow of the water. The Godavari canals were accordingly examined from their pick-up weir at Madmeshwar lake to mile 31 on the Left Bank Canal and mile 49 on the Right Bank Canal. Similarly the Pravara Right Bank Canal was examined from its head-works for 18 miles. The Pravara Left Bank Canal, being still under construction, was not examined.

The weeds discovered were the following :—

(1) *Potamogeton perfoliatus*, Linn.

(2) *Potamogeton pectinatus*, Linn.

(3) *Vallisneria spiralis*, Linn.

(4) *Hydrilla verticillata*, Casp.

(5) *Naias* (?) species.

(6) An alga, resembling *Oedogonium.*

With the exception of the alga, the weeds mentioned are plants rooted in the soil, with their shoots rising into the water to various heights. *Potamogeton perfoliatus* (Plate VI), is the most serious pest, and the impeding of the flow in the canals is due to it.* This plant has a creeping rhizome, two to four inches below ground, from the nodes of which slender adventitious roots penetrate deeper into the

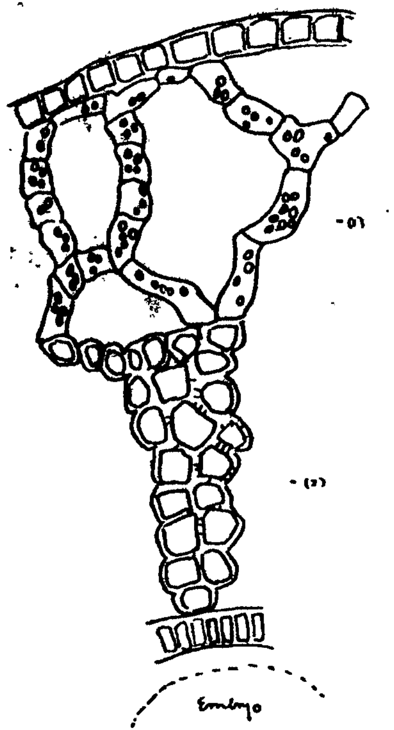


Fig. 1.

Transverse Section of Fruit coat of *Potamogeton perfoliatus*, showing
(1) starch containing floating tissue, and
(2) protective sclerenchymatous sheath.

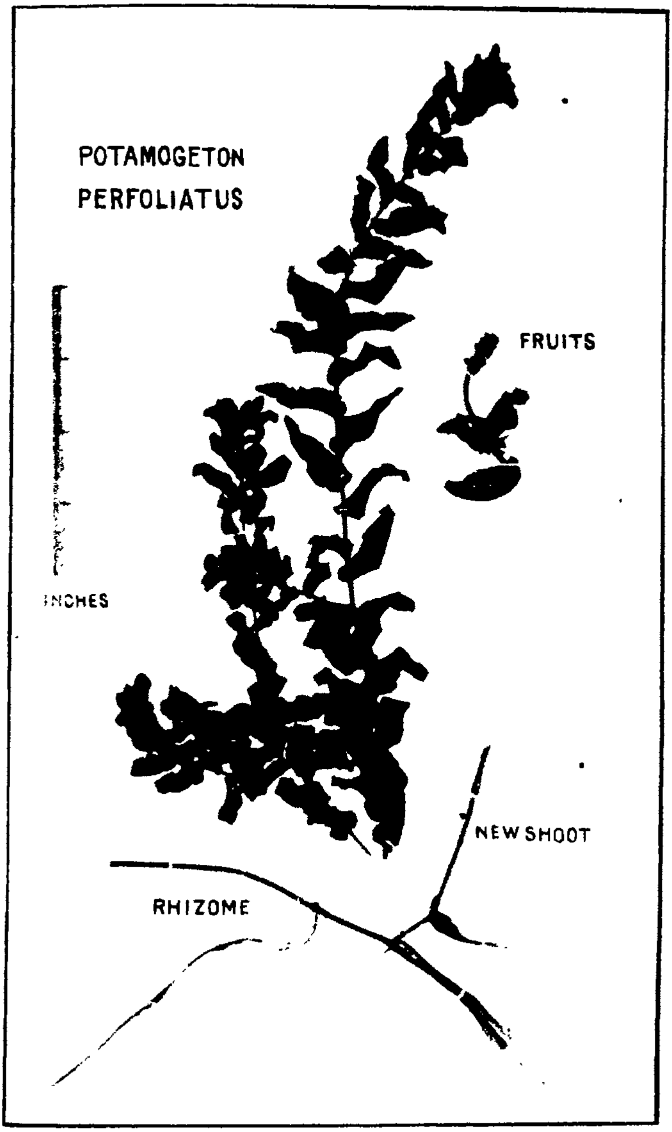
× 124.

Semi-diagrammatic.)

Fig. 2.

Plant of *Potamogeton pectinatus* 17 days after germination of resting tuber ; two ungerminat tubers attached. Natural size.

(Semi-diagrammatic.)



Potamogeton perfoliatus.

soil. The growth of this rhizome appears to be monopodial. The stems arising from its nodes may be of great length. One taken at random from Madmeshwar lake measured 12½ feet from root to tip, the branches and leaves being confined to the top 2 feet. In the 49th mile of the Godavari Right Bank Canal, in water 10 feet deep, two stems taken at random measured 12 and 10 feet respectively with branches and leaves on the terminal 1½ feet. It is unnecessary to give a detailed botanical description of the plant, but points of ecological interest must be considered. Among these, the reproduction of the plant is of the first importance. As already mentioned, the creeping stem forces its way through the soil, sending up new above-ground stems. Reproduction by fruits appears to take place freely. In the Madmeshwar lake many plants of *P. perfoliatus* were in flower or fruit. The small compact spikes stand about one inch above the water. The method[1] of pollination is by wind, and judging from the copious formation of fruits, conditions are favourable. Some of the fruits fall off from the spike and float for a time, and it may be that the whole spike also becomes detached, but this has not yet been observed by the writer. The fruits are 1 mm. × 2 mm. × 2 mm., ovate and pointed in shape, and very thick coated. Fig. 1 shows a cross section of such a fruit with floating and protective tissues. The length of time that these fruits float and the factors affecting it have not yet been determined. This point is important, especially in the present case, where the regulators of the pick-up weir are so arranged as to draw off the surface water only.

It is probable that the Godavari canals have been infected from the Madmeshwar lake by the drifting down of these floating fruits. Leaving this point for the moment let us see if there is any discoverable reason for the extraordinary prevalence of *Potamogeton perfoliatus* in the said lake. The weir which is the cause of the formation of the lake was completed a few years ago. After its completion, a considerable area of previously dry land was submerged and one village had to be vacated. In the first year after the

1 Knuth, *Handbook of Flower Pollination* (Answorth Davies), vol. III, p. 507.

completion of the weir no weeds were observed in the lake. The exact date of their appearance is doubtful. It is possible that fruits of *Potamogeton perfoliatus* from plants in higher pools of the Godavari drifted down into the lake. The newly submerged land would be, as far as aquatic plants were concerned, *a denuded area*, and invasion would be easy. It is interesting to note that the portions of the lake occupied by weeds correspond roughly to the recently submerged areas, while the beds of the Godavari and Kadwa rivers, running through the lake, are clear of weeds. At the same time there are clear patches of water close to weedy areas which cannot be thus easily accounted for. It may be that at such points the substratum is not suitable for the growth of the rhizome.

The freedom of the river beds from weeds is probably due to the greater depth, and possibly to the greater opacity of the water. The influence of the Godavari is felt more in the Right Bank Canal and, if the water reaching that canal is coming unusually directly from the river channel, then the water is more muddy and at the same time more free of floating fruits of *P. perfoliatus*. Such a direct flow appears to have occurred in 1915, weed growth in the Right Bank Canal having been considerably retarded during September and October, although other conditions appeared normal.

The weed grows in water from 1 foot to 20 feet deep. This latter figure is not the maximum depth at which it can grow, but is merely a deep sounding taken casually in a weed area in the Madmeshwar lake. Scott Elliot[1] reports *Potamogeton* at 26 feet in Bruyant, France.

Variations of turbidity or velocity of water seem to have little effect on the distribution of the weed. The leaves occurring on the last 2 feet of the stem are always just below the surface and hence get plenty of light even if the water be muddy. The weed was found in water of all velocities from zero to 4 feet per second and thrives equally well in them all.

It is a curious circumstance that the weed occurred also here and there in borrow-pits beside the canal but having no direct

[1] Scott Elliot, *Modern Botany* (1910), p. 132.

connection therewith. There are three possible explanations of the infection of these borrow pits. The fruits may have been carried (1) on the feet and feathers or in the stomachs of aquatic birds, or (2) in mud on the feet of cattle, or (3) they may have come from bunches of the weed piled on the banks at the time of cleaning of the canals. The fruits may then have been washed or blown down into the pits.

Complete closure of the canal for a prolonged period would doubtless kill the weed, but there is so much land under perennial irrigation from the canal that a prolonged closure is impossible. A closure which is sufficient to kill the exposed stems does not affect the under-ground rhizomes, which begin growth when water is once again let down the canal.

The vegetative growth of the weed is considerable from November to February and is at its maximum during December and January, just after its fruiting period in November. During the hot weather the vegetative growth diminishes, and is more or less dormant during the rains. In this respect, this aquatic weed forms a remarkable contrast to most of the land vegetation of its neighbourhood.

It is possible that the fall in temperature during the rains is the factor that checks weed growth. The factor of extra silt and consequently greater opacity of the water must also be taken into account. Only experimental evidence, however, can determine which of these factors is the more important.

Any methods for controlling this weed must, as far as these observations go, aim at (1) the prevention of fruit formation in the Madmeshwar lake so as to avoid further infection of the canals; (2) the repeated cutting or dredging by suitable apparatus of the weed in the lake to prevent its further spread therein; (3) the extirpation of the rhizomes of the plants now established in the canal. Means to attain these three ends are being considered.

Of the other weeds, *Hydrilla*, *Naias* (?) and *Vallisneria* were found in Madmeshwar lake completely submerged and out of sight in 4 feet of water. None of them were in fruit. They occurred at various points in the canals but were not serious pests.

Potamogeton pectinatus was found in flower at three points in the canal. It was found also in the lake. On account of its linear leaves, it does not hold up the water in the same way as *Potamogeton perfoliatus*. *Potamogeton pectinatus* has peculiar vegetative reproductive bodies not mentioned by Hooker, Cooke, or Woodrow, but briefly referred to by Continental writers.[1] These bodies are small rhizomes consisting of closely packed tubers; each tuber having on one side a shoot ready to start into growth, and on the other a slender internode connecting it with the next tuber. Small chains of these tubers were found both floating in the water and buried in the soil of the canal. The author was absolutely ignorant of their relationships until he grew one experimentally and got from it an unmistakable plant of *Potamogeton pectinatus*. Fig. 2 on p. 66 shows the plant produced. The germinating of such resting-bodies at this season tallies with the cycle of growth already noticed in which the monsoon is the resting season for such aquatic plants.

In the Pravara Right Bank Canal the weeds were much fewer, and the head-works, which is comparatively small, showed only one specimen of *Potamogeton pectinatus* and no *Potamogeton perfoliatus*. The latter is, however, found in the canal and the infecting fruits doubtless come from higher up the river.

The whole question of the control of the weeds of these canals constitutes a most interesting problem in applied ecology.

ADDENDUM.

Since the above paper was written for the Indian Science Congress, further collection of weeds from the Madmeshwar lake, and observation of specimens grown in tubs have brought to light the fact that the floating stems have the power of producing rooted branches adventitiously. It is likely that these branches later on fall off or are detached by the decay of the parent branch. This discovery makes the task of eradication of the weeds even more

[1] Engler and Prantl, Natürlichen Pflanzenfamilien II Teil, I Abteilung p. 195 Handwörterbuch der naturwissenschaften, X Band, 519.

difficult since it will be necessary not only to prevent fruit formation, but to check the drifting down of these rooted and detached branches.

Fruits sown under water in November 1915, germinated in March 1916.

The artificial conditions in the tubs induced flowering after four months.

It appears also that there are probably three varieties of *Potamogeton perfoliatus* in the lake. Specimens of these are now being grown to determine if they are genetically distinct.

IRRITABILITY OF THE BLADDERS IN UTRICULARIA.

BY

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A SPECIES of *Utricularia* very near *flexuosa* is a free-floating insectivorous plant (found in a tank in Madras). The leaves are finely dissected. The bladders that entrap insects hang by short stalks from the axes of the leaves (Plate VII, fig. 1). They are oval in shape and are broader in one direction than the other. The mouth of the bladder is horse-shoe shaped, with the bend of the horse-shoe posterior and the base anterior. The mouth is surrounded by a ridge which is produced at the two ends of the base of the horse-shoe into two stout projections from which branched hairs start. These hairs are referred to by Darwin as the antennæ. Except along the base of the horse-shoe the ridge is fringed with long pointed hairs (Plate VII, fig. 2, and Plate VIII, fig. 1).

The valve or trap-door of the bladder is attached to the inner and lower margin of the ridge all along the base of the horse-shoe and to a very short extent along the sides. In the living condition the valve is not flat as is commonly supposed but is transversely convex and dome-shaped when looked from above. The apex of the dome lies very near the bend of the horse-shoe so that the curve of the arch rises very gradually from the base up to very near the bend of the horse-shoe and then has a sharp fall (Plate VIII, fig. 2). From the apex of the dome start six or eight long pointed hairs arranged in two sets with a short space between. The hairs stretch towards the base projecting slightly upward and are nearly as long as the

Fig. 1.

Fig. 2.

[illegible]

[illegible] inches). The larger [illegible]

[illegible] entrap insects hang by [illegible]

[illegible] (Plate VII, fig. 1). They are oval [illegible]

[illegible] than the other. The mouth [illegible]

[illegible] with the bend of the horse-shoe [illegible]

[illegible] is surrounded by [illegible]

[illegible] at the base of the horse-shoe [illegible]

[illegible] their stems. These [illegible]

[illegible] Except along the [illegible]

[illegible]

the valve is not flat [illegible]

[illegible]

PLATE

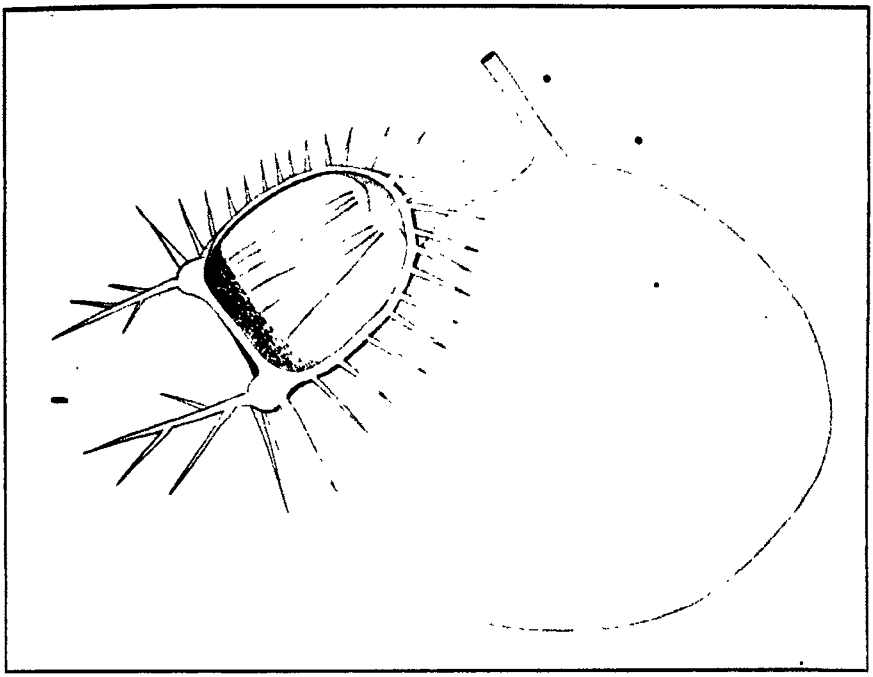
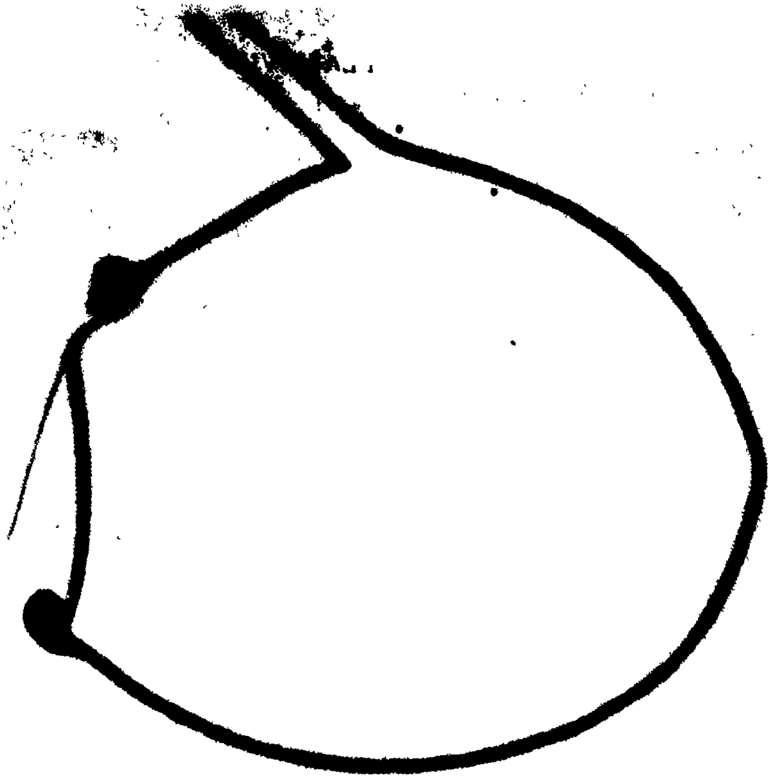


Fig.



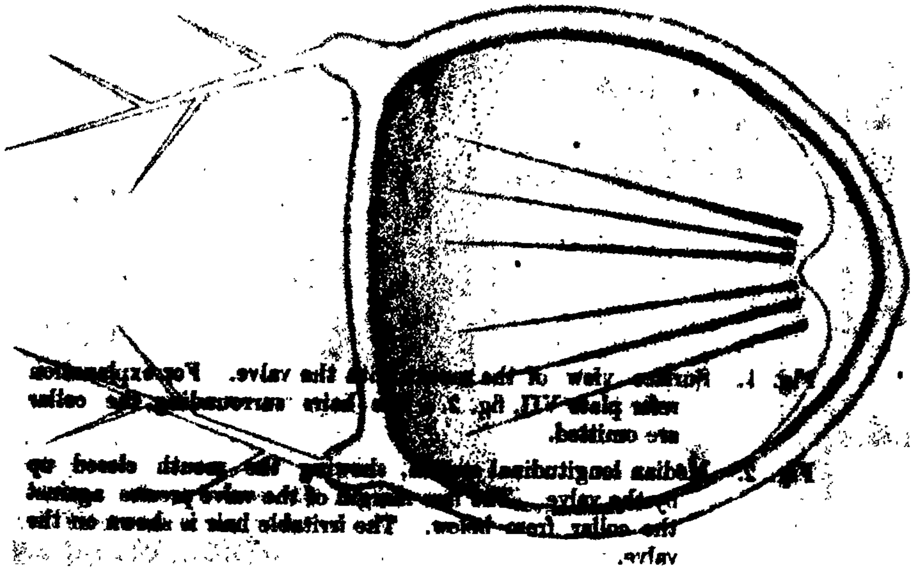
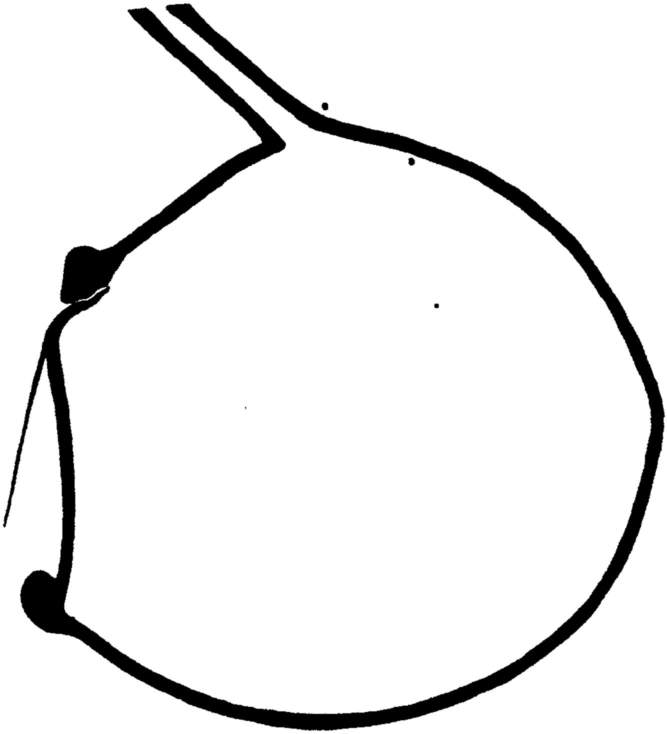
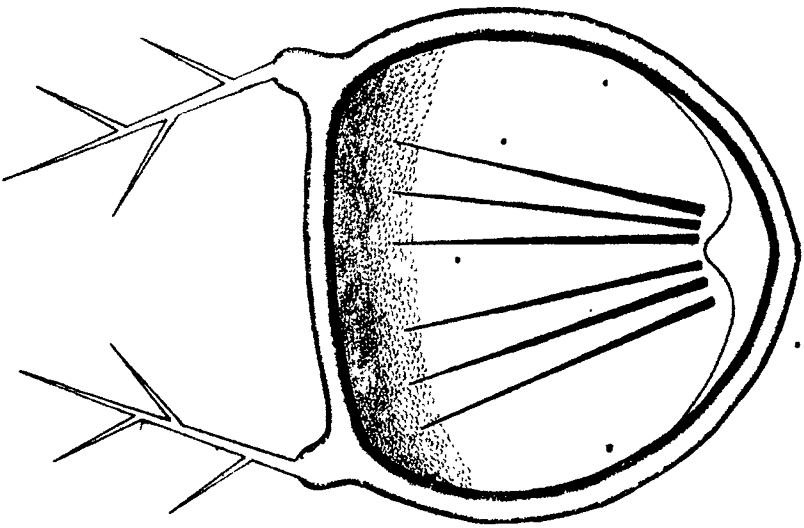


Fig. 1. Surface view of the mouth with the valve. For explanation refer plate VII, fig. 2. The hairs surrounding the collar are omitted.

Fig. 2. Median longitudinal section, showing the mouth closed up by the valve. The free margin of the valve presses against the collar from below. The irritable hair is shown on the valve.





valvé. The portion of the upper surface of the valve nearest the base of the mouth is densely clothed with club-shaped hairs which are glandular and secretory. The valve has a thin margin which goes below the ridge of the mouth all round and is tightly pressed against it.

Darwin has shown that small crustaceans and other animalculæ are found inside these bladders and that, since they cannot escape once they are caught, they die and decay. The decayed animal matter is absorbed by peculiar quadrifid hairs, found on the inner surfaces of the walls of the bladders.

My attention was drawn to a peculiar behaviour of this plant, when I was distributing specimens to my class for studying the structure of the bladders. As the specimens were lifted out of water to be placed in smaller dishes, they made light crackling sounds resembling the ticks of a watch. The sounds were unaccountable by anything I knew of the structure of the different parts of the plant. After a series of observations, they were located as coming from the bladders. The state of the bladders before and after lifting the plants out of water, gave the clue. When the plants had been allowed to remain quiet for two or three days in water, among the full grown bladders nearly 25 per cent. were found to be half filled with air and half with water. Nearly 50 per cent. were found to be completely filled with water and in some of these, the small organisms entrapped may be seen. The rest were nearly empty, with the walls closely adpressed against each other, so that there was very little cavity inside. and the bladder as a whole was biconcave.

The first two kinds of bladders with the walls convex and with the cavity inside filled with water or water and air, I will designate as "full." The last with its walls concave and with very little cavity, I will call "hungry." In every case the valve or trap-door was tightly pressed up against the rim of the mouth. When the plants were lifted up and replaced in water, there were very few hungry bladders left and in their places were now found some completely filled with water and others with water and air. There was no change in the full bladders. From this it

was inferred that the hungry bladders, when they were disturbed and came in contact probably with the leaf segments or other parts of the plant, opened out and let in water or water and air. Hence I suspected that the bladders were irritable and that the valve was very likely not simply a passive elastic door to be pushed in as Darwin supposed by an unwary or inquisitive animalcule, but an active trap-door which helped the bladder to forcibly suck in its prey.

As to the manner by which the animalcules make their way into the bladders, Darwin says " Animals enter the bladder by bending inwards the posterior free edge of the valve which from being highly elastic shuts again instantly. As the edge is extremely thin and fits closely against the edge of the collar, it would evidently be very difficult for the animal to get out when once imprisoned and apparently they never do escape. As I felt much difficulty in understanding how such minute and weak animals as are often captured, could force their way into the bladders, I tried many experiments to ascertain how this was effected. The free margin of the valve bends so easily that no resistance is felt when a needle or thin bristle is inserted. A thin human hair fixed to a handle and cut off so as to project barely $\frac{1}{4}$ of an inch entered with some difficulty, a longer piece yielded. On three occasions, minute particles of blue glass (so as to be easily distinguished) were placed on valves while under water and on trying gently to move them with a needle, they disappeared so suddenly, that not seeing what had happened, I thought I had flirted them off ; but on examining the bladders they were found safely enclosed. The same thing occurred to my son who placed little cubes of green boxwood on some walls and thrice in the act of placing them on or whilst gently moving them to another spot, the valve suddenly opened and they were engulfed. He then placed similar bits of wood on other valves and moved them about for some time and they did not enter." " To ascertain whether the valves were endowed with irritability, the surfaces of several were scratched with a needle or brushed with a fine camel-hair brush so as to imitate the crawling movements of small crustaceans, but the valve did not open. We may, therefore, conclude that the

animals enter merely by forcing their way through the slit-like orifice, their heads serving as a wedge." "But," says Darwin, "I am surprised that such small weak animals should be strong enough to act in this manner, seeing that it was difficult to push in one end of a bit of hair ¼ of an inch long." Darwin evidently came to the above conclusion quite half-heartedly and he missed the correct solution by a hair's breadth.

I will first corroborate Darwin's idea that it is unlikely that such small and weak animals should be strong enough to enter the bladders by pushing in the valve, and then try to explain the mystery of the particles of blue glass and boxwood. I tried to get an idea of the pressure the valve was able to withstand before it yielded and was pushed in. For this purpose, I used a spring which was fixed to a stand by one end. To its other end a piece of cork, with a small metal cup on its top and a needle stuck in at the bottom, was attached, so that the blunt end of the needle hung free. Below this was placed a Ziess's hand microtome which has a flat circular top, with a hole in the centre, through which the block-holder can be moved up and down by a micrometer screw. A bladder was cut across and the upper half, with the valve, was made to rest on its cut end, inside a narrow glass ring fixed to a slide. The ring was filled with water so that the cut bladder was immersed in water. The slide was placed on the microtome and slowly raised until the free end of the needle rested on the valve just touching it. Care was taken to see that the end of the needle did not come in contact with the ridge surrounding the mouth. The orifice was big enough to admit the end of the needle freely. Sand grains were now added to the metal cup until the lid just gave way. The weight of the sand grains which was 270 mg. gave an approximate idea of the pressure that the lid was able to withstand. This is likely not accurate, as here, the weight of the sand grains included not only the upward pressure of the valve, but also the weight necessary for the extension of the spring. To avoid it, as I thought, the action of the spring was reversed in this manner. The weight necessary for stretching the spring to a known distance was first calculated and then in the stretched

condition the needle was made to rest on the valve. Now the valve was gradually raised until it gave way. The distance to which the spring was raised to effect this, was made out and from it the weight supported by the valve was calculated. The weight thus got was 250 mg.

Now, let us consider the pressure the organisms can exert on the valve. Though it was not possible to get an accurate estimate, the following considerations, I expect, will give an approximate idea of the pushing force of the crustaceans and others, found inside the bladders. The force, that these organisms can exert, can be derived in three ways : firstly, their weight ; secondly, the momentum with which they dash against the valve ; and thirdly, the activity of their own muscles or any other structures corresponding to them.

The first factor, namely the weight, is quite negligible, since it will be greatly or fully counteracted by the buoyancy of water. As regards the second source, namely the momentum, the habit of these organisms, when they approach the bladders, is of great interest. I have spent a long time watching for the suction of the animals into the bladders. Whenever an animal approached a bladder, its quick motion was stopped and it went round as if it were brousing along in search of food and in no case was there an aimless or unwitting impact with the valve. Darwin says "It is difficult to conjecture what can attract so many creatures, animal and vegetable feeding crustaceans, worms, and various larvæ to enter the bladders. Perhaps small aquatic animals habitually enter very small crevices like that between the collar and the valve, in search of food or protection." My observations lead me to believe, though I am not yet in a position to prove definitely, that the attraction for these animals lies in the secretion of the clubheaded hairs found profusely near the base of the horse-shoe on the valve. Since the animals when they are near the bladder move about very slowly, the second source of energy is also not of any consequence. The third source, that of muscular power, is hard to get at and can only be guessed ; but a different consideration will, I think, put this source out of court. The distribution and direction of the long-pointed hairs round the ridge are such that entrance into the horse-shoe is

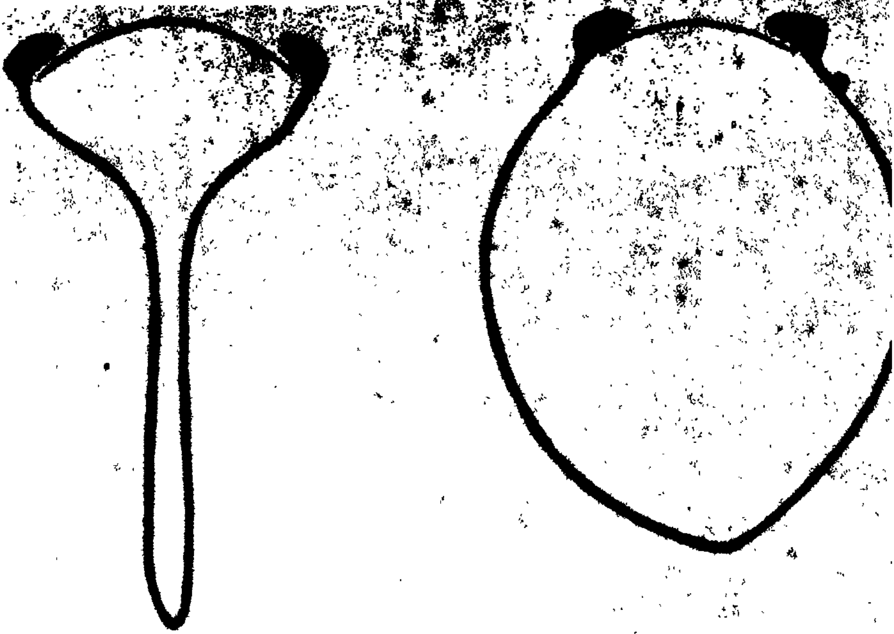
easy only through an arch formed by the antennæ or the very long branched hairs at the base of the horse-shoe. Now if an animal enters through this arch, it will necessarily come against the sharp points of the hairs which stretch from the apex of the valve towards this entrance. So it appears impossible for the animal to get at the edge of the valve and push it in. The above considerations, I hope, show that the presence of the animals inside the bladders cannot be due to their pushing their way in.

To see whether the suspicion that the bladders were irritable had any basis, the following experiments were done. First I selected some of the "hungry" bladders and irritated with a needle the different parts of the ridge, round the mouth and the valve. When the hairs at the apex of the dome of the valve were irritated, the adpressed sides shot out suddenly with a sharp explosive sound and the bladder got filled with water or air. I repeated this over and over again, so as to assure myself that I did not really push the valve in, but only irritated the hairs, and in the case of every hungry bladder the same reaction followed. No reaction occurred when any other parts of the region were irritated, so that I was able to assure myself that these particular hairs were the irritable hairs. Then I wanted to see whether similar conditions obtained when an animal was caught inside the bladder. It was found impossible to manœuvre the organisms to the bladders and, though I observed for a long time, I was not able to see an organism actually sucked in. But the critical question, whether a bladder is capable of sucking in the organisms if they irritate the hairs on the valve, was settled by another means. Once a dead fly, more or less in a putrifying condition, was found floating on the water in one of the dishes. I took the front half of the fly at the tip of a needle and irritated the hairs of a hungry bladder with the head of the fly. To my joy, the whole object was immediately sucked in. This set at rest my doubts as regards the capacity of the bladders to suck the organisms in, as the biggest of the crustaceans found inside were not more than $\frac{1}{3}$ of the head of the fly in size.

I wish to draw attention to the fact that the above experiments were done with the hungry bladders only. The full bladders

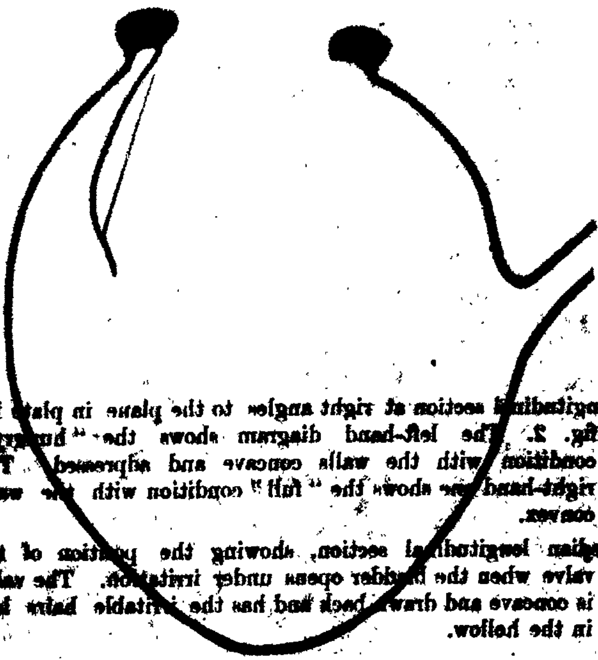
do not react to irritation. This explains the mystery of the disappearance of the particles of blue glass and boxwood in some cases and not in others. I take it that the bladders that swallowed the particles were 'hungry' and those that did not were 'full.' The same fact also explains the negative results obtained by Darwin when he irritated the bladders, as nearly 75 per cent. of the bladders in a plant are in the 'full' condition and the 'hungry' bladders are generally very few. It may also be due to the fact that the reaction to irritation is extremely quick and easily escapes notice.

A few words about the mode of action under irritation. Owing to the quickness of reaction, it is impossible to observe directly the opening and closing of the valve. When the valve of a full or non-hungry bladder is pressed down with a needle as far as it could go, the irritable hairs project right in the centre of the opening. If an animal is sucked in when the valve is in this position, it should be either impaled on the hairs or the hairs should be broken. But I could never believe, that in such a delicate mechanism, this flaw could ever occur. The explanation was arrived at rather accidentally. In an idle mood I pressed out the contents of a full bladder with a pair of pincers. The contents came out through a slit formed by a portion of the margin of the valve being pushed out. When the pressure was relieved, the valve fell back quickly to its place and no water entered from outside; but some air escaped from the intercellular spaces in the walls of the bladder and filled up the cavity. Then, I once again pressed out all the air and over again when more air came in. When the air was driven out twice or thrice, the bladder assumed the hungry condition. When I irritated the hairs, it reacted in the normal manner. I got very much interested and the whole operation was thrice repeated with the same bladder. The valve went in once again under irritation but never came back and the bladder was left wide open. When I looked through the open mouth, I could not see the irritable hairs and the passage was perfectly clear. It was then that the proper position of the irritable hairs, when reacting to irritation, was shown. On examination, it was found that the convex valve had become concave and boat-shaped, and the hairs were found safely



a

Fig. I



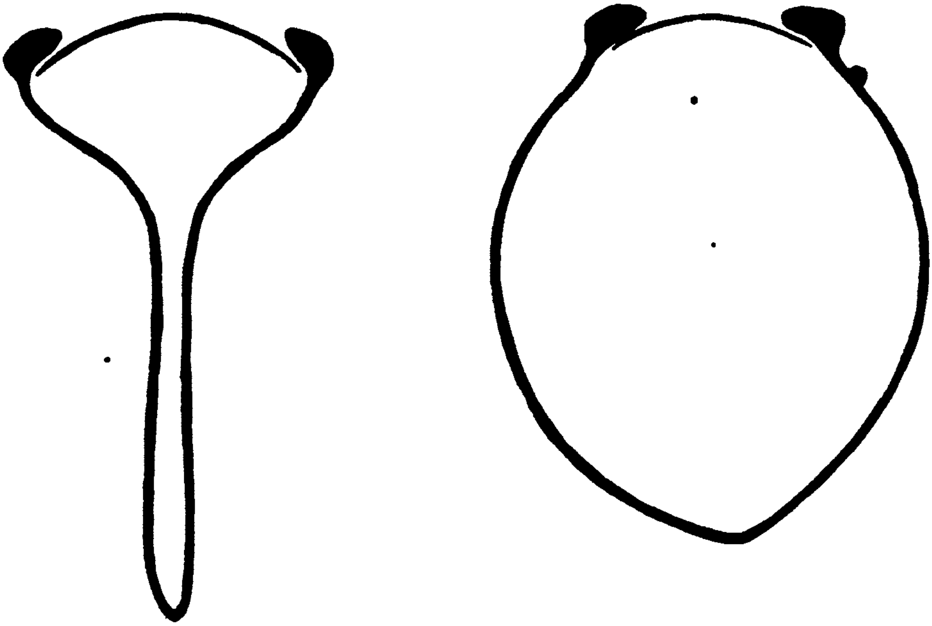


Fig. 1

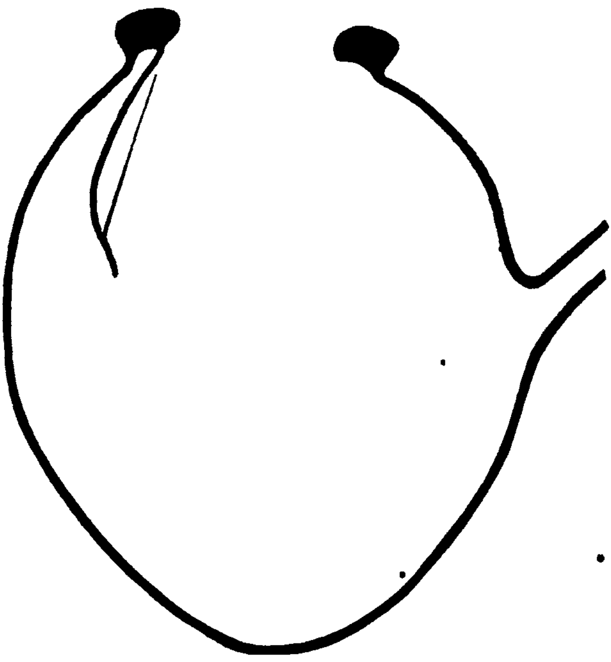


Fig. 2.

laid at the bottom of the boat. The orifice was fully open without any obstruction. (Plate IX, fig. 2.)

The nature and arrangement of the cells that go to make up the valve, the irritable hairs, and the ridge are very interesting. Their relation to the functions performed is under investigation.

MODELS TO ILLUSTRATE SEGREGATION AND COMBINATION OF MENDELIAN CHARACTERS.

BY

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It is not proposed in this paper to expound the principles of heredity discovered by Mendel. My object is merely to explain the working of models devised by me to demonstrate the behaviour of hereditary characters that conform with Mendel's principles, as they are transmitted from one generation to another.

I have taken glass beads to represent the determiners of hereditary unit characters. A coloured bead is used to represent the determiner of a dominant character. A colourless bead of the same shape and size is used to stand for the corresponding recessive, if the presence and absence hypothesis of dominant and recessive characters is to be illustrated. A certain modification of the entire model is devised to illustrate the working of the determiners of heredity, when the recessive ones are supposed to have a definite existence.

I have represented the idea of there being two determiners or a double dose of a dominant character in an individual by taking two coloured beads which are in every way identical. The single dose condition is represented by two beads of the shape and size but only one of them is coloured while the other is colourless. The nil dose or recessive condition is represented by two uncoloured beads. The use of any beads whatever to represent recessive determiners when they are conceived to have no existence at all is

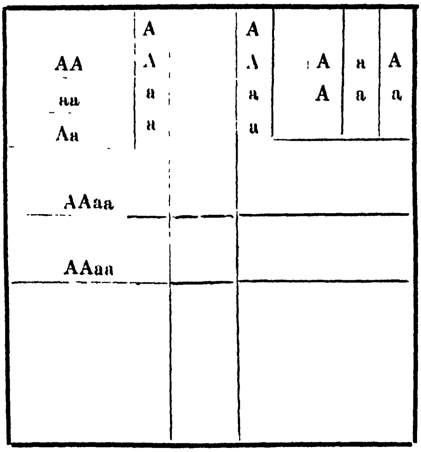
justified only on the score of convenience afforded in working the model.

The idea of indivisibility of the determiners and their segregation in the sexual cells involves the reduction in the sexual cells of a double dose when it is present in an organism to a single dose, and the formation of two sorts of sexual cells in equal numbers one carrying a single dose and the other a nil dose when the organism itself has got only one dose. This implies the existence of sexual cells of only two types with reference to a given determiner, one type carrying a single dose of it and the other none of it. Thus there are three types of organisms represented by the conventional symbols **A A, A a,** and **a a,** and called homozygous or pure dominant, heterozygous or hybrid dominant, and recessive which is always pure; but there are only two types of sexual cells, *viz.*, **A** and **a.** This fact is generally embodied in the doctrine of purity of gametes. Segregation is commonly spoken of in Mendelian literature, following Mendel's own conception of "pairs of differentiating characters and their mutual separation in the sexual cells" as "the dissociation of the allelomorphic or alternative characters in the constitution of the gametes," or symbolically the separation of A a from each other. The separation of A A and of **a a** (Mendel conceived of **a a** not as an absence but as a presence) also from each other was not noticed by Mendel, and has also apparently escaped the attention of most writers on Mendelism. The composition of different zygotes and of their gametes with reference to one character may be represented thus—

Zygotes	A A	A a	a a
Gametes	all A	A and a in equal numbers	all a

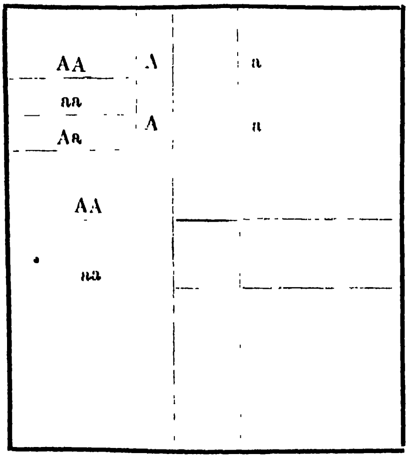
In my model which consists of a square frame work standing erect and carrying strings of beads the composition of the different types of organisms and of the gametes is shown by beads on different strings. The strings carrying the beads for gametes of one parent cross those of the other parent, and the composition of the resulting zygotes is shown by moving the beads to the points of intersection.

The following diagram which deals with the consideration of one character only will render clearer what I have just stated.



Note. The beads in the top left-hand square represent the zygotes and those in the top right-hand square the gametes produced by these zygotes.

It may be further simplified as given below which requires only fourteen beads in all.



When two characters are considered conjointly there would be nine (3^n, n being the number of characters considered as stated by Mendel), different forms of zygotes represented by the symbols AA BB, AA bb, aa BB, aa bb, AA Bb, Aa BB, Aa bb, aa Bb and Aa Bb, and there would be four (2^2) different forms of gametes, *viz.*, AB, Ab, aB and ab.

In the model the strings of beads representing the gametes should be in pairs, one string for the determiners of each character. Since there are four different forms of gametes there should be four pairs of strings. The four vertical pairs would cross the four horizontal ones and thus there would be sixteen groups of crossing, each group consisting of four crossings. The formation of zygotes is represented in the central square by moving the requisite beads to the points of intersection. If it is desired to reproduce the conventional arrangement when demonstrating the effect of selfing of AaBb or of crossing of a zygote AaBb with another which is also AaBb, the four types of gametes on the four pairs of strings should be arranged in the order **AB, Ab, aB** and **ab** from left to right on the vertical strings, or from above downwards on the horizontal strings.

In the demonstration of the working of three characters taken conjointly, there would be twenty-seven (3^3) possible forms of zygotes to be considered. These may be arranged as follows though any other order would serve the purpose.

Group I	AA BB CC		
,, ,,	AA BB cc	AA bb CC	aa BB CC
,, ,,	AA bb cc	aa BB cc	aa bb CC
,, ,,	aa bb cc		
Group II	AA BB Cc	AA Bb CC	Aa BB CC
,, ,,	AA bb Cc	aa Bb CC	Aa BB cc
,, ,,	aa BB Cc	AA Bb cc	Aa bb CC
,, ,,	aa bb Cc	aa Bb cc	Aa bb cc
Group III	AA Bb Cc	Aa BB Cc	Aa Bb CC
,, ,,	aa Bb Cc	Aa bb Cc	Aa Bb cc
Group IV	Aa Bb Cc		

In the model, **ABC** are represented by three kinds of beads which differ in colour, shape, and size, and **abc** by corresponding beads which are colourless. The twenty-seven genotypes fall into four groups according to their behaviour in breeding when selfed and I have assigned to each of them a separate corner in the model. In the first group there are eight genotypes which are quite constant. These are placed in the left-hand top corner. The second group which contains twelve forms includes genotypes in which one of the three characters will split. The third group of six forms contains two of the three characters splitting. The last group which contains

only one form has none of the characters constant. The abov grouping also brings out the frequency of the occurrence of differen forms when Aa Bb Cc is selfed. The resulting combinations forr a series of 64 in which the eight genotypes of the first group appea once only, the twelve genotypes of the second group appear twic only, the six types placed in the third group appear four times, an lastly, the single type in the fourth group appears eight times The following table makes this point clear :—

8×1	8
12×2	24
6×4	24
1×8	8
	64

If it is desired to bring out the phenotypic composition as well it may be done by adding eight squares to the model in any fashior whatever. I would suggest their provision in an oblong frame witl eight compartments added to the model at the top of it. Th twenty-seven genotypes may be arranged in eight phenotypic group as follows :—

1. Phenotype ABC having eight genotypes.

   AA BB CC
   AA BB Cc   AA Bb CC   Aa BB CC
   AA Bb Cc   Aa BB Cc   Aa Bb CC
   Aa Bb Cc

2. Phenotype ABc having four genotypes.

   AA BB cc   AA Bc cc   Aa BB cc   Aa Bb cc

3. Phenotype AbC having four genotypes.

   AA bb CC   AA bb Cc   Aa bb CC   Aa bb Cc

4. Phenotype aBC having four genotypes.

   aa BB CC   aa BB Cc   aa Bb CC   aa Bb Cc

5. Phenotype Abc having two genotypes.

   AA bb cc   Aa bb cc

6. Phenotype aBc having two genotypes.

   aa BB cc   aa Bb cc

7. Phenotype abC having two genotypes.

   aa bb CC   aa bb C

8. Phenotype abc having one genotype.

   aa bb cc

So far I have dealt with simple factors. An effective demonstration of complementary factors is obtained by using tiny bits of sponge dipped in appropriate chemical solutions instead of beads. Thus bits of sponge dipped in phenolphthalein and caustic potash solutions may be used to demonstrate the production of coloured flowers by crossing two white forms. Other phenomena of Mendelian inheritance such as cumulative factors, inhibitory factors and gametic coupling can as well be demonstrated on the same principles. I propose to deal with these in detail in a subsequent paper, as also with the modification required to be made when the recessive characters are supposed to be due to the presence of definite recessive determiners.

THE CORRELATION OF RAINFALL AND THE SUCCEEDING CROPS WITH SPECIAL REFERENCE TO THE PUNJAB.*

BY

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Introductory. In the first application of the method of correlation to the problem of the numerical measurement of the dependence of crops on rainfall in India, only the general effect of the whole summer and winter rainfalls on the autumn and spring harvests respectively was considered. In the present paper the effect of the distribution of rainfall in time is more specifically dealt with, and, too, the more important crops have been treated separately; both being very necessary steps towards the complete determination of the character of the harvest from the antecedent rainfall.

Increasing attention has been devoted of late years to attack on the same problem by similar methods in other countries, more particularly in America, and there has been obtained a sufficient number of high coefficients of correlation to encourage further investigation on the same lines.†

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* This paper is also published as a Memoir of the Meteorological Department of the Government of India.

† The more notable values obtained hitherto are:—

(1) A double correlation coefficient of +·80 of Spring rain and accumulated temperature with outturn of hay from clover and rotation grass for Eastern England. Hooker.—*Journal Roy. Stat. Soc.*, 15-1-1907.

(2) A total correlation coefficient of +·73 between the rainfall of October to March and the unirrigated matured area of the Spring harvest for the Sialkot district of the Punjab, and a double correlation coefficient of +·80 for similar data for the Delhi district. Jacob.—*Memoirs of the Asiatic Society of Bengal*, 3-2-1909. (*Continued on page* 87).

The tract selected: Jullundur Tahsil. The tract I have dealt with is the Jullundur Tahsil of the Jullundur District situate in the Doaba between the rivers Beas and Sutlej. The area of the Tahsil is 428 square miles of which practically 290 are cultivated, and it is divided into three Assessment Circles, which are roughly homogeneous in respect of their soil, climate, and their courses of husbandry. There are no canals and as a rule very little flooding, so that the problem of rainfall effect is not too complicated. But there is a very large number of wells, and during the last 30 years more wells have been steadily added to both the Dona Lehnda and Dona Charhda Circles, and this means that there is a concomitant diminution of unirrigated crops, for which allowance has to be made in considering the variation in the areas sown each harvest on unirrigated land. Thus in the Dona Charhda Circle every fresh well sunk has meant that on the average 2·2 acres cease to be classed as unirrigated for the purposes of the Spring harvest. Of this diminution a loss of :—

0·66 acre	per new well falls on unirrigated				wheat sown,
1·20	,,	,,	,,	,,	wheat and gram,
0·18	,,	,,	,,	,,	gram alone,

and the balance of ·16 acres on other crops.

The countervailing gain in Spring irrigated crops is however no less than an additional 7·4 acres for each additional well, of which 3·36 acres per well, or rather less than one-half, has been an increase in wheat sowings. Before the correlation of the areas sown with the rainfall are worked out, the crude figures must in all cases be corrected by the appropriate factors, these being slightly different for each of the three Assessment Circles.

Distinction between the two problems—sown area and yield. Two entirely distinct problems present themselves if we propose

(3) A correlation of −·69 between accumulated temperature and potato yield Warren Smith.—*U. S. Monthly Weather Review*, May 1911

(4) A correlation of −·70 between the effective rainfall of July 21 to August 20, and the yield in corn in Ohio. Warren Smith —*U. S Monthly Weather Review*, February 1914.

(5) A correlation of ·88 between rainfall and temperature in April to September and the yield of cotton in Texas J. B. Kincer —*U. S. Monthly Weather Review*, February 1915.

to forecast the amount of crop of any harvest, and these are :—

(1) The determination of the area sown with each class of crop.

(2) The determination of the percentage of the crop which is likely to come to maturity, or, in other words, the yield or outturn per unit of area.

The first problem, which is, for not too great a cycle of years, in the main a problem of rainfall and temperature, is also an economic and psychological problem—prices of seeds, scarcity of labour, population, mortality, the standard of living, the number of plough cattle, mechanical aids to cultivation, and political events—all having contributory effects. Yet, unless the fluctuations in these subsidiary causes are very violent, they will not mask the first order effect of rainfall, and the proper method is to deal with the large effects first, and then proceed to disentangle the residual effects. This is the invariable scientific practice in those cases, for example in astronomy, in which we cannot control the phenomena.

The second problem, the determination of the yield of each crop per acre, is much less an enonomic problem than the preceding one, especially in dealing with unirrigated crops which are not much manured or weeded, and is really a joint problem of meteorology, subsoil physics, and plant biology. It is a statistical problem only on account of its complexity ; and the more physical and biological laws can be applied to it, the smaller will be the residual unexplained effects to which it will be necessary to apply statistical methods.

PREDICTION OF AREAS SOWN.

Correlation of rainfall and sown areas. I take first the problem of predicting the extent of sowings, and give the total correlations of some only of the crops which have been considered for each Assessment Circle, namely, for *chahi* (well-irrigated) wheat, wheat and gram unirrigated, and all unirrigated crops together, for the Spring harvest based on the figures of the thirty years 1886-1915.

The correlations are :—

		July	August	September	October
Chahi wheat ...	Dona Lehnda	-0·38	-0·25	-0·52	... ..
	„ Charhda	......	-0·28	-0·53	-0·34
	Sirwal ...	... ..	-0·01	-0·50	-0·39
Barani wheat and gram.	Dona Lehnda ...	0·18	0·21	0·54	
	„ Charhda ...	.. ..	0·13	0·54	0·19
	Sirwal ...	......	0·16	0·27	.. .
All Barani Spring crops.	Dona Lehnda ..	0·21	0·04	0·37	
	„ Charhda ...	... ..	0·17	0·48	0·33
	Sirwal	... ..	-0·06	0·48	... .

The July and August coefficients are in the neighbourhood of 0·20 with a probable error of ± 0·12, or, on the simple theory of probability, the odds in favour of these correlations being significant are 7 to 1. The simple theory, however, by no means gives a favourable enough estimate of the odds when we find coefficients of about the same magnitude repeated again and again. In fact the repetition of the correlations for three different areas, supposing the sown areas in each case are unassociated except on the score of a more or less common rainfall, makes the odds nearly 350 to 1. So that I think that we may justly conclude that the correlations with July and August rainfalls are significant. In any case it is highly probable that they are significant, as the rainfall in these months is a true contributory cause of the autumn sowings of September, October, and November.

The correlations of sown area with September rain are in the neighbourhood of 0·50 with a probable error of ± 0·09, so that the simple odds in favour of the significance of this correlation are over 80,000 to 1, so that this coefficient is undoubtedly significant. The frequency with which nearly the same value of the correlation is found for this and other districts of the Punjab makes the odds much greater even than this.

The correlations for October are on an average about 0·23 with a probable error of ± 0·11, or the odds in favour of their significance are 18 to 1.

A further point of importance with regard to the correlation with September rain is that the odds are 9 to 1 against its being as

low as 0·325, and we are not likely to be wrong if we say that it lies between 0·4 and 0·6. For lower correlations we cannot predicate such narrow limits between which the correlation coefficient is likely to lie.

The coefficients are the simple or so-called total correlation coefficients, but they do not represent the actual rainfall effect and it is necessary to eliminate the error due to the fact that the rainfalls in the different months are themselves correlated, and so it is possible that the area sown is spuriously correlated with the August rainfall simply because it happens to depend on the September rain, which in its turn is correlated with the August rainfall.

If the rainfalls in August, September, and October (July rainfall has been left out of account because of the doubt of the magnitude of its effect on autumn sowings) are positively correlated *inter se*, then this fact will have given a fictitiously high value to all the correlations: but, if on the other hand the rainfalls are negatively correlated among themselves, the true magnitude of the crop correlations will have been masked, and we may have considerably to increase the total correlations previously found. This latter is actually the case. The correlations of the rainfalls are:

August with September	0·37
,, ,, October	−0·10
September with October	0·13

So that it is clear that the true or so-called net coefficients of correlation are markedly larger than the values previously stated. The valuation of the net coefficients of correlation is a somewhat laborious process, and for the Jullundur data I have limited myself to the two cases of greatest interest, namely, for well-irrigated wheat and for all unirrigated crops together.

Prediction for Chahi wheat. I take firstly the case of well-irrigated wheat in the Dona Charhda Circle for which the average area sown in the last 30 years is 19,100 acres, with a standard deviation of 4,080 acres or 21·3 per cent. The net correlations of the area sown each autumn are as follows:—

With August rainfall	−0·79
,, September ,,	−0·86
,, October ,,	−0·74

These average at about 0·80 with a probable error of ± 0·08, and the odds are thus over 20 to 1 against the coefficients being as low as − 0·60 in absolute value, and nearly 200 to 1 against their being as low as − 0·5, so that we may say that these coefficients are almost certainly greater than 0·6.

From these correlations we determine the equation expressing the area sown with wheat on well-irrigated lands in terms of the rainfall departures from the mean, namely:

$$S' = 18{,}890 - 570\ D_8 - 750\ D_9 - 4{,}300\ D_{10},$$

where D_n is the departure of the rainfall of the nth month from the average rainfall of the month.

The equation shows what an enormous effect rain in October has in causing the cultivator to abandon wheat sowings on well-irrigated lands: in fact an inch of rain in October would throw out nearly 6 acres of well-irrigated wheat, as against one acre thrown out by an additional inch of rain in August.

The equation must not, however, be interpreted to mean that every successive increment of rain will throw out further equal amounts of well-irrigated wheat, as the relation between the rainfall and the area sown is certainly not linear when we come to large departures from the average. All that we can assert from the equation is that rainfall of the quantity and distribution that fell during the years 1885—1914 in August, September, and October did, on the whole, have the effects noted. Of course in considering what effects rainfall in the different months has on well-wheat sowings we must remember that it is much more usual to have a departure of one inch of rain in August or September than in October, and properly to compare the effects of rainfall as it did occur in the last thirty years we must multiply the regression coefficients of each month by their respective average rainfalls. We find thus that actually the relative effects of August, September, and October rainfall were as 2 : 3 : 1, the reason for the low October effect being due to the fact that it is the exception to get rain in October at all. If it does fall it has, as we have seen, a much greater effect than rainfall in the previous months in diminishing sowings of well-irrigated wheat.

When the appropriate correction for the number of wells has been introduced the final formula of prediction for the sown area of *chahi* wheat is :—

$$S = 3{\cdot}6\,(w\text{-}5540) + 26{,}910 - 570R_8 - 750R_9 - 4300R_{10},$$

where R_n is the total rainfall in the nth month, and w is the number of wells in the Assessment Circle.

The multiple coefficient of correlation of sown area and the 'weighted' area is 0·89, so that the prediction formula, so far as a linear expression can give the relationship, is a good one.

From this formula the sown area has been calculated for each year from 1885—1914 and the results are shown graphically in Diagram I, which shows also the actual sown areas.

The correspondence between the observed and calculated results is seen to be distinctly close. The probable error of the prediction is $0{\cdot}67 \times \sigma_{1\cdot234} = 1050$, or 5·6 per cent. of the mean.

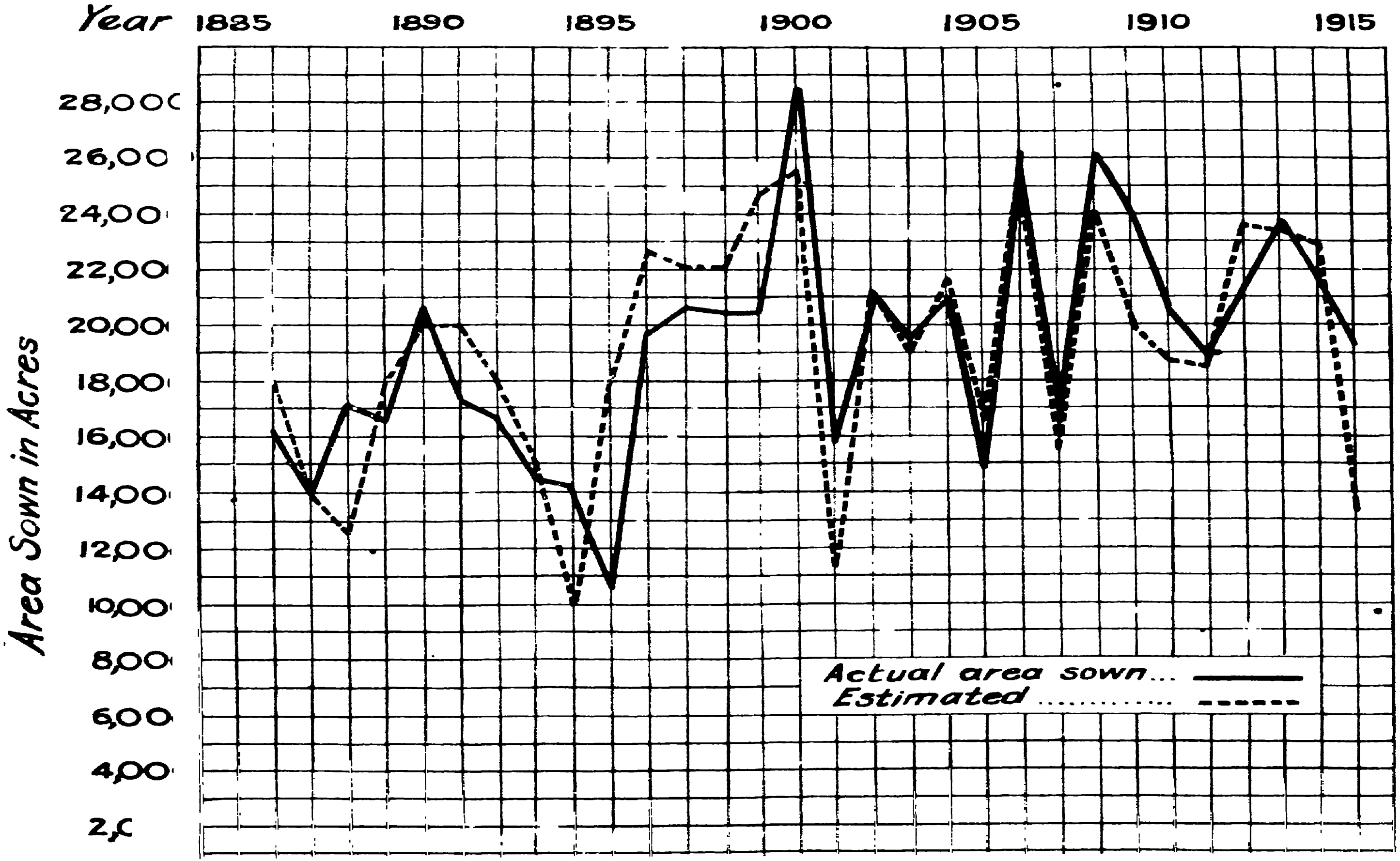
Constancy of other crops. A very important fact may here be referred to, namely, that if we group together all well-irrigated Spring crops excluding wheat, and wheat and gram and form a class of 'other crops' which consists mainly of the fodder crop, senji, melon, tobacco, and other vegetables,* the sown area of this class after the correlation for numbers of wells has been applied is remarkably constant from year to year having a coefficient of variation of only 5·9 per cent. as against one of 21·9 per cent. for well-irrigated wheat, so that the prediction from an appropriate rainfall formula would have a probable error of about 2 per cent. only.

Prediction for all barani rabi crops. The next case treated is that of all unirrigated (*barani*) Spring crops taken together.

The prediction of the sown areas of individual unirrigated crops is very desirable, but except for the principal crop, wheat and gram combined, the problem will require a finer analysis than by the total rainfall of the month. Thus the 30th of September is a critical time. If sowing conditions are favourable before that date, a great deal of gram is likely to be sown, but if suitable rain falls after that, gram is almost always combined with wheat. Wheat

* This group of crops consists of those grown for local consumption of man and beast and are very little affected by external supply and demand.

Dona Charhda CHAHI WHEAT.



in particular requires very favourable conditions if it is to be sown on *barani* land, and an examination of monthly rainfall does not suffice to show the fluctuations in the area sown, which in all three parts of the Tahsil shows a steady fall from 1885 onwards with a minimum between 1900 and 1905 and a very marked rise in the last 10 years.

The regularity of the change suggests a secular cause such as Dr. Shaw's 11 years' periodicity from wheat in England. At any rate the general trend of the data can be fitted with a smooth curve.

Parabolas fitted by the method of least squares are fair representations, but would certainly break down for extrapolation purposes.

For the sown areas of all unirrigated Spring crops together the net correlation coefficients are :—

With August rainfall	= + 0·57
,, September ,,	= + 0·72
,, October ,,	= + 0·59

The combined coefficient of correlation is 0·77 so that fair prediction is to be anticipated. Taking the coefficients of the linear regression formula, and multiplying them by the appropriate constant, the expression

$$\cdot 147\ R_8 + \cdot 53 R_9 + 2\cdot 66 R_1$$

is obtained which may be called the weighted rainfall. If the weighted rainfall is taken as the abscissa and the area sown corrected for the number of wells as ordinate we get a distribution of the kind as shown in Diagram II which clearly indicates that to a second approximation the data can be fitted with a curve of the form

$$y^n = ax - bx^2,$$

and after a number of trials the curve

$$y^3 = 34x - 1\cdot 7x^2$$

was found to be a fair but not a good approximation to the changes. The curve rises abruptly at the origin, but it would have been better to make it rise abruptly at 2″ of the rainfall, which is about the minimum required for any sowings at all. It reaches a maximum at 30″ of weighted rainfall, that is to say,

beyond that, more rainfall would interfere with sowings. About the same maximum was found for data in the old Delhi District. The problem however must be attacked by a systematic curve-fitting method, which should substantially reduce the probable error of prediction which is 0·675 × 5700 = 3840 acres or 9 per cent. of the mean, an appreciably larger error than in the case of irrigated wheat, although the coefficient of variation is about the same, 22 per cent., in both cases. Even as it is, the prediction afforded is a distinct advance on existing practice.

Prediction of Outturn.

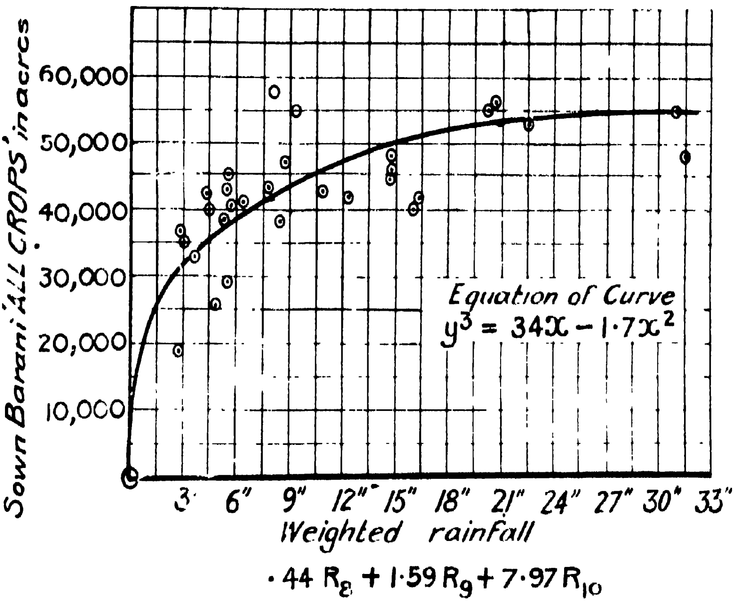
Nature of problem. The next step after finding out how much crop is sown is to find out how much of it is going to come to maturity, and that is as for human beings, both a bathmic and an environmental problem, condition of seed, state of the seed bed, and the treatment and climate from the time of sowing to the time of harvesting, being the factors to be taken into account.

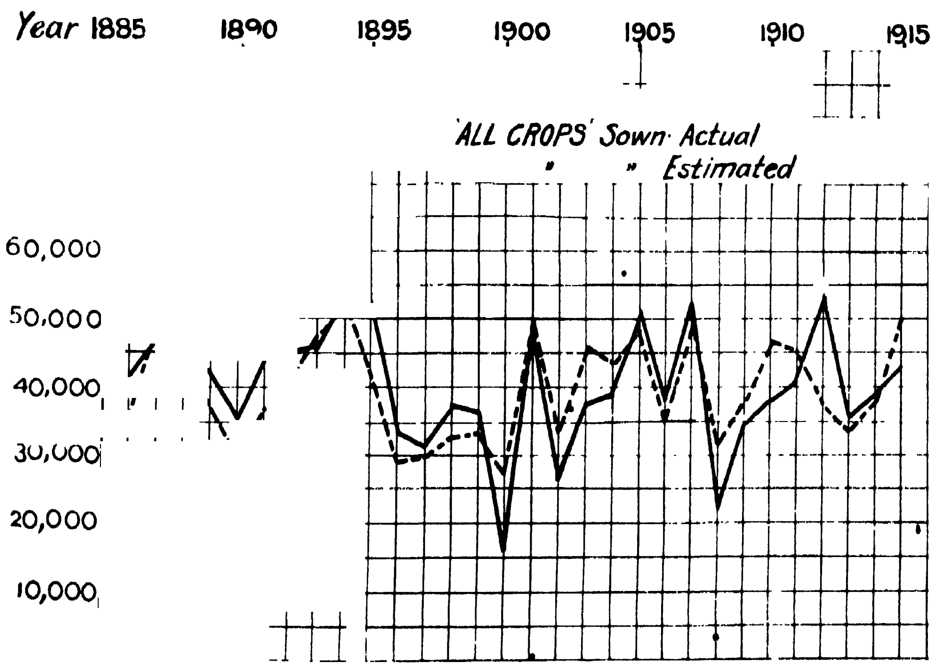
In the present paper unirrigated wheat only is dealt with by the statistical method, and the condition of seed has not for the moment been taken into account; but the state of the seed bed which depends, in the main, on the September and October rainfall, is taken into account as well as the rainfalls in each of the subsequent winter months, November to March.* The antecedent rotational crop which is a very important factor in considering individual fields is a quite subsidiary point in the aggregate over such a large area as an assessment circle, in which there will be many fields in different stages of the crop rotation. As a matter of fact, unirrigated wheat is generally sown after a 10 months fallow and is followed by *charri*, *moth*, or *guara*, in the subsequent June or July (*dofasli dosala*) or on the better class of unirrigated (*barani*) soils, wheat is sown year after year (*ek fasli ek sala*) with no intermediate crop. The outturn is determined in the Punjab Revenue Papers from the

* An analysis which aimed at completeness would naturally include not merely rainfall but all climatological factors, such as temperature, sunshine, precipitation in the form of dew, evaporation, wind, and so forth, defect or excess of which may on occasion reduce an otherwise promising crop to a very poor condition. Given the opportunity the analysis can be so completed.

DIAGRAM II.

Dona Charhda ALL BARANI RABI CROPS SHOWN.





area of the crop which fails to come to maturity, the so-called *kharaba* which is merely the Patwari's estimate of the deficiency of the particular field below what he considers a normal value.

His estimate is checked by various Revenue officials of higher grade, but it still remains subject to a very large personal equation. In particular during the last 15 years there has been much greater liberality in allowing *kharaba*, and in dealing with the statistics the last 30 years have been divided into two periods. The results based on the second period are probably the more reliable. Crop experiments are, as at present conducted, of a very perfunctory kind, and two or three of them for each principal crop per Tahsil, would be required to get results truly indicative of the character of the harvest. It is much to be regretted that a proposal to do away with crop experiments altogether has been mooted. It is quite as important that accurate outturns should be determined for crops grown by cultivators under normal conditions, as for crops grown for special test purposes by the Agricultural Department.

Prediction by multiple correlation. Taking the figures for *kharaba* as we have them the correlations of rainfall and failed area for the various crops are :—

Correlations of percentage kharaba with rainfall in the winter months.

	Assessment Circle	September	December	January	February	March
Chahi wheat	Dona Lehnda		-0·36	-0 19	-0·27	0 27
	,, Charhda	0·41	-0·46	+0 01	-0·21	-0·36
	Sirwal	..		..		
Chahi all crops	Dona Lehnda			..		
	,, Charhda	0·46	0 39	0·18	-0·25	-0·43
	Sirwal	-0·08	-0·05	+0·17	-0·02	0·15
Barani wheat	Dona Lehnda		-0·31	-0·16	0 19	-0 07
	,, Charhda	-0·37	-0·40	-0·16	-0·26	0·26
	Sirwal	-0·12	-0·07	+0·23	0·02	-0·14
Barani wheat gram	Dona Lehnda		-0·13	0·14	-0 19	0 23
	,, Charhda	-0·37	0·34	-0·19	0·31	-0·35
	Sirwal	-0·54	-0·33	-0·11	0·37	-0·41
Barani gram	Dona Lehnda	...				
	,, Charhda	-0·43	-0·51	-0·19	-0·31	-0 35
	Sirwal	..				
Barani all crops	Dona Lehnda	..	-0·23	-0·20	-0·14	-0·22
	,, Charhda	-0·40	-0·40	-0·17	0·32	0·24
	Sirwal	-0·42	-0·32	-0·07	-0·26	0·23

The Dona Lehnda results are for the 30 years 1886-1915. For Dona Charhda and Sirwal for 1901-1915.

A noticeable feature of the figures is the high negative correlation with September rainfall, additional evidence, were any necessary, of the value of a moist seed bed for germination.

I have not had sufficient time at my disposal to discuss in great detail the results for all three Assessment Circles, and for this reason it was necessary to limit the further analysis to a single crop and a single assessment circle. Accordingly the most important crop, wheat, has been selected, and that Assessment Circle in which the rain gauge is situated.

I emphasize only the Dona Charhda figures for unirrigated wheat which are :—

	September	December	January	February	March
Whole period 1886—1915 .	−0·30	−0·30	−0·27	−0·19	−0·24
First " 1886—1900 ...	−0·25	−0·25	−0·46	−0·02	−0·19
Second " 1901—1915 ...	−0·37	−0·40	−0·16	−0·26	−0·26

These figures are consistent *inter se* and with all the other Circles and crops and their significance is accordingly greater than it would be if measured merely by their probable errors.

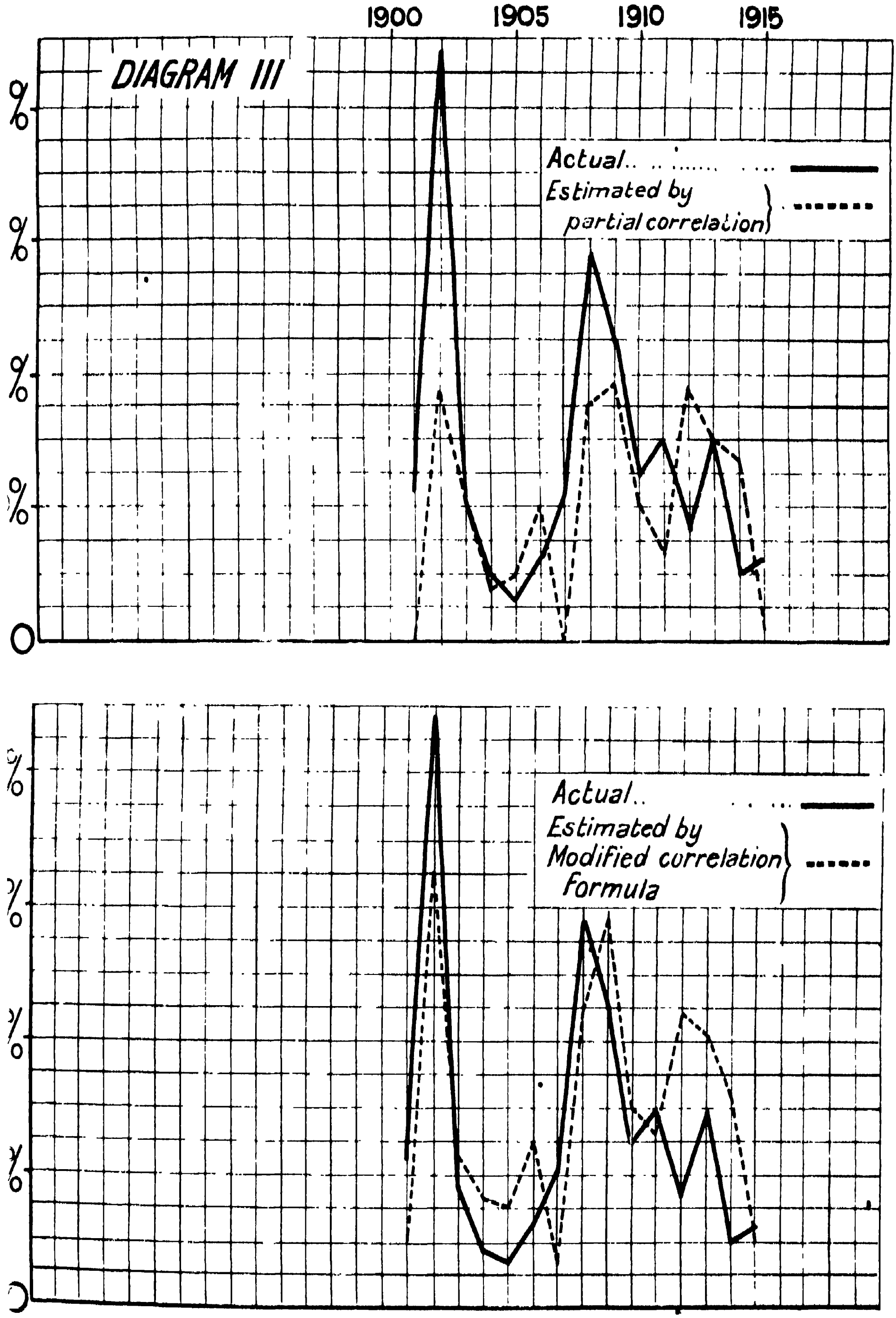
On the figures of the last 15 years I have calculated a provisional regression formula based on the erroneous assumption that the rainfalls in these five months are not correlated to each other.

Actually there is no significant correlation between the rainfalls of December and February, January and February, February and March.

In fact the February rainfall seems a very detached effort, but there is a substantial correlation in the rainfalls in the other months. The concordance between calculation and fact is shown in Diagram III. The agreement would have been much better had these mutual rainfall correlations been taken into account, but a multiple regression formula based on six variables takes a long to evaluate time and on account of pressure of much other work I had to abandon it.

Kincer's method. Moreover, Dr. Simpson having drawn my attention to an alternative, and in some ways a preferable method

Dona Charhda. WHEAT KHARABA.



of dealing with the problem, developed by J. B. Kincer in the *U. S. Monthly Weather Review* of February 1915 for dealing with the yield of cotton in *Texas*, it seemed of importance to apply the method to yields of Indian crops. Kincer's results being so good that a correlation of 0·88 is obtained.

Kincer assumes that the most favourable conditions for cotton are the normal ones, and that any departures from these, whether above or below, whether of rainfall or temperature, are harmful. There would seem to be *a priori* justification for this in dealing with a crop with centuries of development in a single place behind it, but expert opinion would be advisable before adopting it for Indian crops particularly for imported plants.

Kincer adopts certain numerical values for the harm done by rain, or heat, or cold, according as a plus deviation follows a plus deviation, a minus a minus, and so on, thus :—

	RAINFALL					
	April	May	June	July	August	September
+ following + or 0 ..	4	8	8	4	4	4
+ „ – ..	4	4	2	2	2	3
– „ – ...	4	5	6	8	10	8
– „ 0 or + ..	2	2	3	6	8	4

Naturally a sequence of months with the same departure from normal is weighted as the most harmful.

He has a similar table for temperature :—

	April	May	June	July	August	September
+ Temperature with 0 or + rain.	1	1	1	1	1	1
+ T with – R ..	1	1	2	2	2	1
– T with – R .	1	3	2	2	2	2
– T with + R	1	4	4	2	2	2

He has in addition certain slight modifications of the value to be introduced when during several months the same conditions obtain.

The values are stated "to have been fixed empirically from a general knowledge of the effect or plant development of certain combinations of weather," but what constitutes a plus, zero or a minus departure is not stated except that 0·3 of an inch of rain less than the normal for April or May is considered as minus.

Application of Kincer's method to unirrigated wheat. In applying Kincer's method to the yield of unirrigated wheat in Jullundur District, it seemed much better to assume that all departures of rain above the normal are beneficial and *vice versâ*, not because this is true for all crops in all places, but because with the soil and rainfall which actually obtain in that district, it is very rare for excess of rain to be markedly harmful.

In order to make the scheme as little arbitrary as possible the rainfall distribution curves have been plotted for each month, and divided into three equal areas which are marked –, O, + respectively.

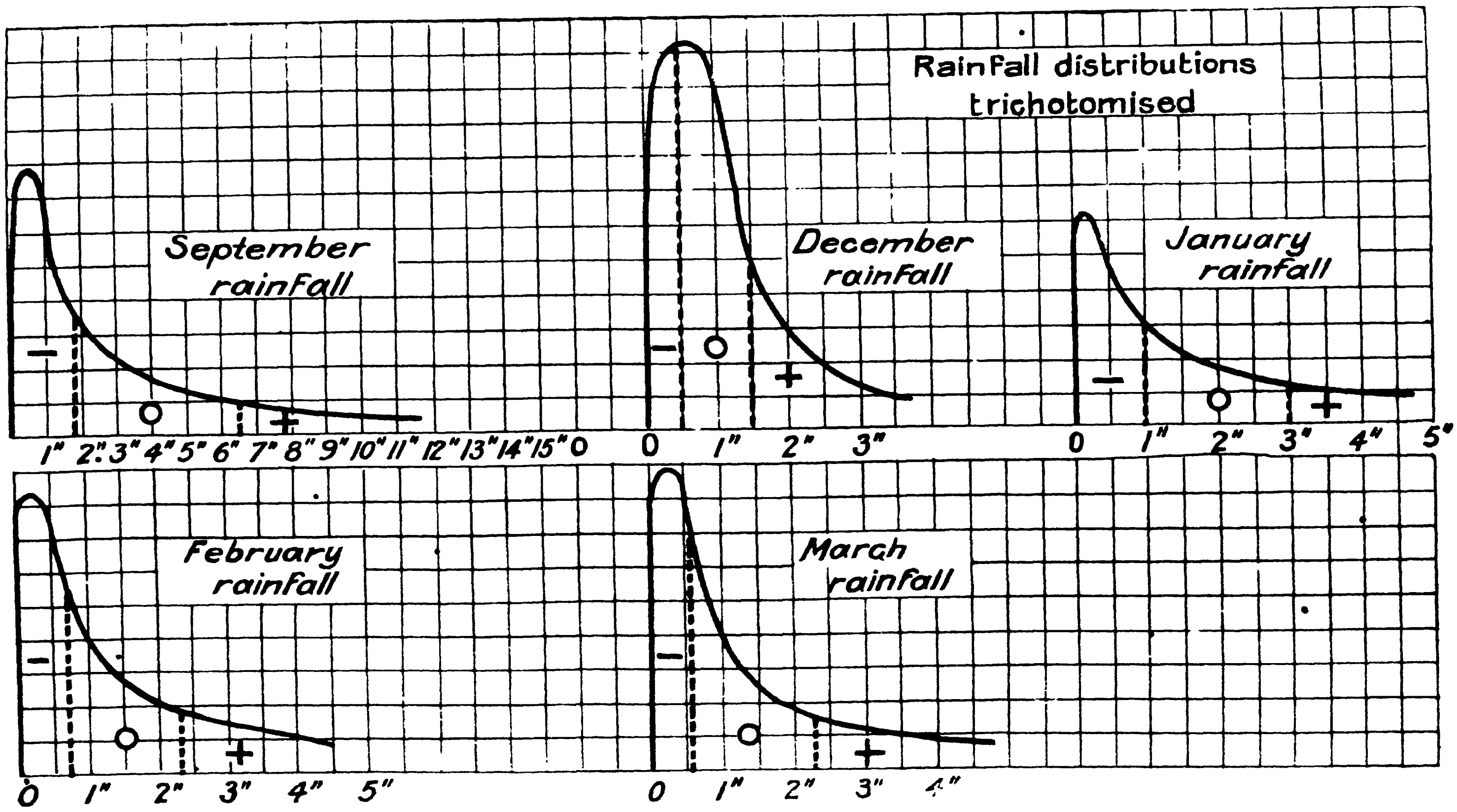
The trichotomy is exhibited in the accompanying Diagram IV. Thus :—

		–	0	+
		Less than	Between	Above
September	...	1″·8		6″·5
October	...	0″·1		0″·5
November	...	0″·1		0″·5
December	...	0″·5		1″·5
January	...	1″		3″
February	..	0″·7		2 ·3
March	...	0″·6		2″·2

Rainfalls in each month are then weighted according to the following scheme (September rainfall weight = 5).

Rain departure for September	Benefit of October and November rain
+	0
0	0
–	20
	Benefit of December rain.
+	1
0	2
–	3

DIAGRA



Rainfall distributions trichotomised
September rainfall
December rainfall
January rainfall
February rainfall
March rainfall

	Rain departure December	Benefit of January rain
+	+	1
	0	2
	−	3
0	+	2
	0	3
	−	4
+	+	3
	0	4
	−	5

		Rain departure January	Benefit of February rain
+	+	+	1
		0	2
		−	3
	0	+	2
		0	3
		−	4
	−	+	3
		0	4
			5
0	+	+	2
		0	3
			4
	0	+	3
		0	4
			5
		+	4
		0	5
			6
	+	+	3
		0	4
			5
	0	+	4
		−	5
		0	6
		+	5
		0	6
		−	7

The only modification which was necessary to this was the addition of the factor 20 to every 0 above 2 in number occurring in the months September, December, January, February and March, thus indicating that long continued normal conditions are, as in the case of cotton in Texas, very favourable.

The weighted rainfall in each month was added together, and a coefficient of benefit B obtained, and this was correlated with the area of unirrigated wheat for 1900-1915. The correlation is -0.91.

even higher than Kincer's figure of 0·88. The formula giving the percentage of failure in terms of the coefficient B is

$$K = 24{\cdot}2 - {\cdot}35B.$$

The *kharaba* calculated from this formula is plotted with the actual figures of *kharaba* in Diagram V. I think the agreement of the two values shows that the formula is a very good one and affords *a posteriori* justification of the hypothesis.

The introduction of suitable corrections for other climatic factors, such as temperature, sunshine, evaporation, precipitation in the form of dew, wind and the like would improve the prediction still further.

Betterment of Prediction.

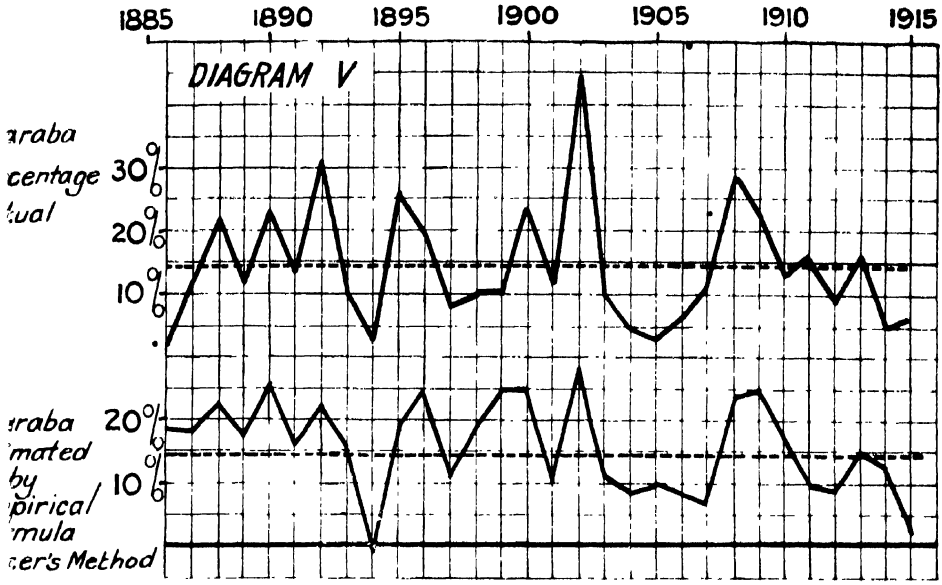
Subsoil water. The method of correlation is not a method apart, dissociated from other methods of analysing observed facts; on the contrary, the more physical and chemical laws we can make use of before we start correlating the better.

For example in forming the prediction equations for sown areas, we have correlated rainfalls in August, September, and October with the areas sown in September, October, and November, but what we really want to know is, what the cultivator has a shrewd knowledge of, when he puts in his crop, and that is the state of the subsoil moisture, and also the temperature of the seed bed.

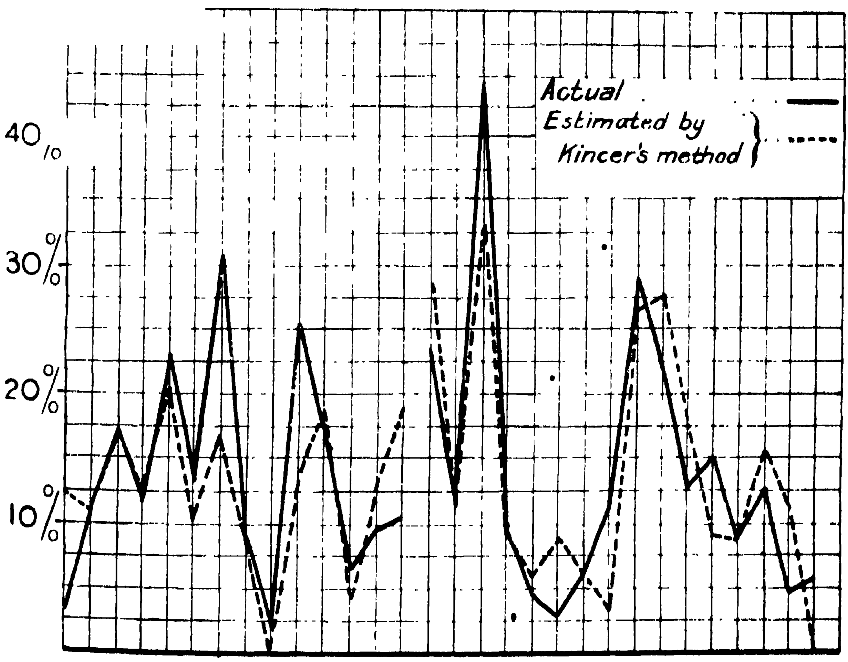
The problem is, given the rainfall and temperature throughout the monsoon period, what is the distribution of the subsoil moisture when *rabi* sowings commence. I have been unable to find even in Leather's valuable researches the complete answer to this question. He has indeed shown,* that if evaporation is an exponential function of the time, the quantity of water in the first seven feet of Pusa soil can be found from the known temperature and humidity from September till June, but as the question of run-off, which in the monsoon is all important, is not quantitatively worked out, it does not seem possible to apply the results without further

* Leather, J. W. Water requirements of crops in India. *Mem. Dept. of Agri. in India Chem. Ser.* vol. I. no. 8.

Dona Charhda WHEAT KHARABA.



WHEAT KHARABA.



experiment to the Punjab. It seems very desirable to repeat the Pusa experiments in all typical Punjab districts, and it should be possible as a result of them to state once for all a formula giving the soil moisture at the close of the monsoon, for each foot of subsoil in terms of the antecedent rainfall and the size and nature of the particles composing the soil.

The complete hydrodynamical solution of the movement of the subsoil water has not so far been obtained, but on the assumption that the velocity is proportional to the first differential of the relative saturation of the soil and that the ratio of surface of all particles per unit of volume to the saturation quantity of moisture is constant, an integrable equation results, for a linear change of particle surface with depth.

This is a great limitation. Further experiment in this country is urgently required, and from a sufficiently extended series of data assumptions could be made leading to a more or less accurate general solution.

Lastly as to the determination of yield, what we want to know is not merely what are the optima conditions of soil moisture and temperature, but what effect defective conditions have. Thus want of water in the first stage of growth is said to mean short stalk, but not necessarily small grain; in the later stages water is essential for grain development.

What is the quantitative expression of this law?

According to Warren Smith, American corn requires between 40 to 80 per cent. of the saturation value of moisture for its most favourable development, but exactly what will be the development of a plant which has, say, 40 per cent. of moisture in one month, 30 per cent. in the next, 20 per cent. in the next, 30 per cent. in the next, and so on?

In particular, what in each stage of development is the minimum requisite to support plant life.*

* Leather's researches throw some light on this problem, Vol. 1, No. 8 of the *Memoirs of the Department of Agriculture in India*, page 146, which shows that for unmanured wheat, an increase of soil moisture from 10 to 20 per cent. increases the grain weight by about 80 per cent.

(*Continued on page* 102).

Plant development. To sum up, the method of correlation enables us to establish prediction formulæ of both sowings and yield, which represent with accuracy the effect rainfall has on the crops. They would undoubtedly be improved by considering the effect, in particular, of prices, crop rotation and temperature, and by incorporating all established quantitative laws as to subsoil moisture and plant development. Even as it is, the formulæ obtained in this paper have a definite practical value which modern statesmanship cannot afford to ignore.

Conclusion.—In conclusion I wish to express my thanks to the kindness of Dr. Gilbert Walker and Dr. Simpson in having most of the many coefficients of correlation calculated.

Between 10 and 20 per cent. the weight of crop increases nearly in a linear fashion with increase of moisture, but though in the case of unmanured wheat diminution of outturn might be linear down to zero moisture it is certainly not so for Leather's experiments in the case of manured wheat, and in particular it is important to know what happens with greater saturation than 20 per cent Even this preliminary knowledge for a pot culture with a percentage saturation kept constant throughout the period of development, would give a function closely correlated with the actual yield.

DIAGRAM VI.

DONA CHARHDA (Rabi Crops Sown.)

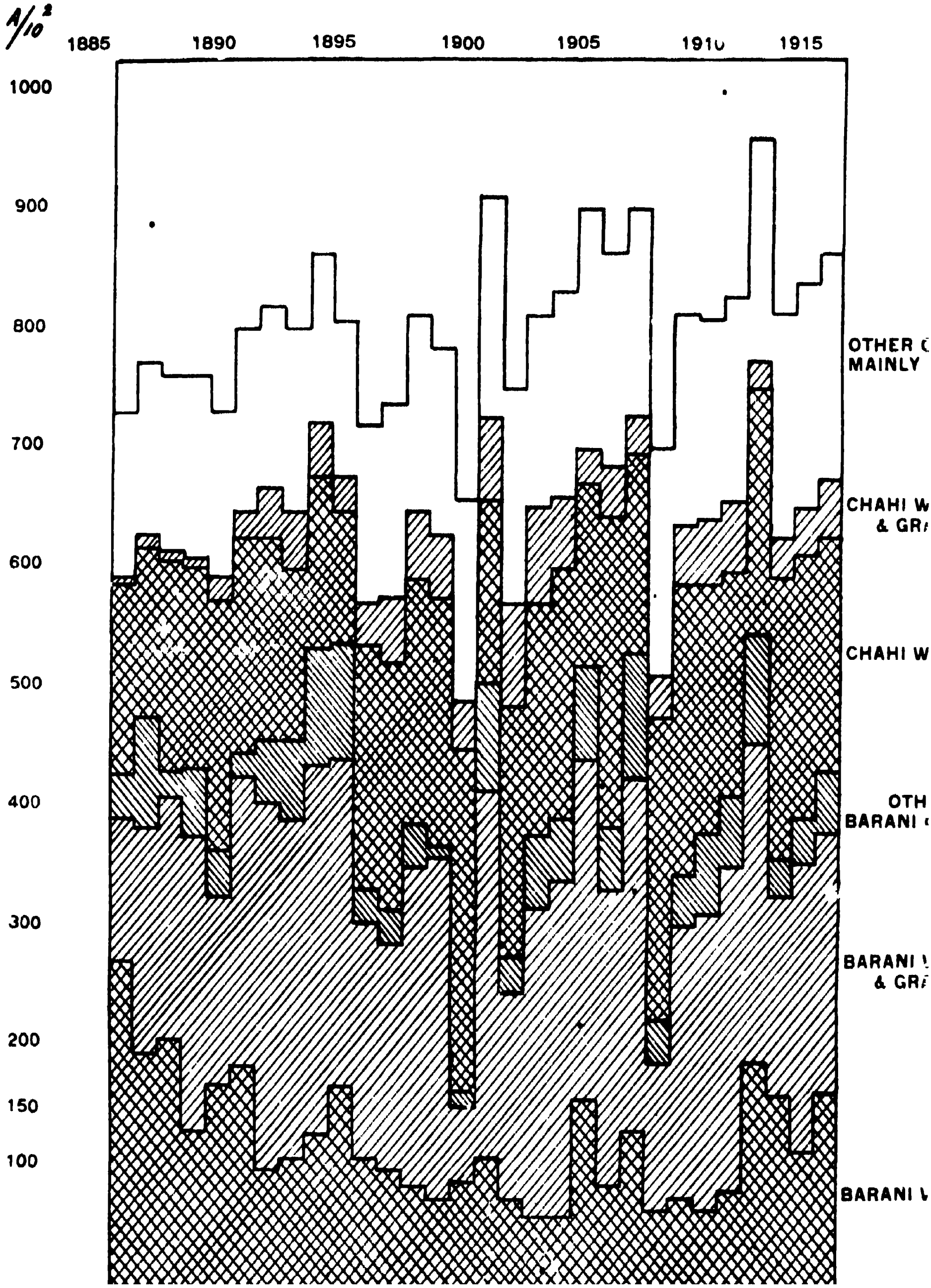
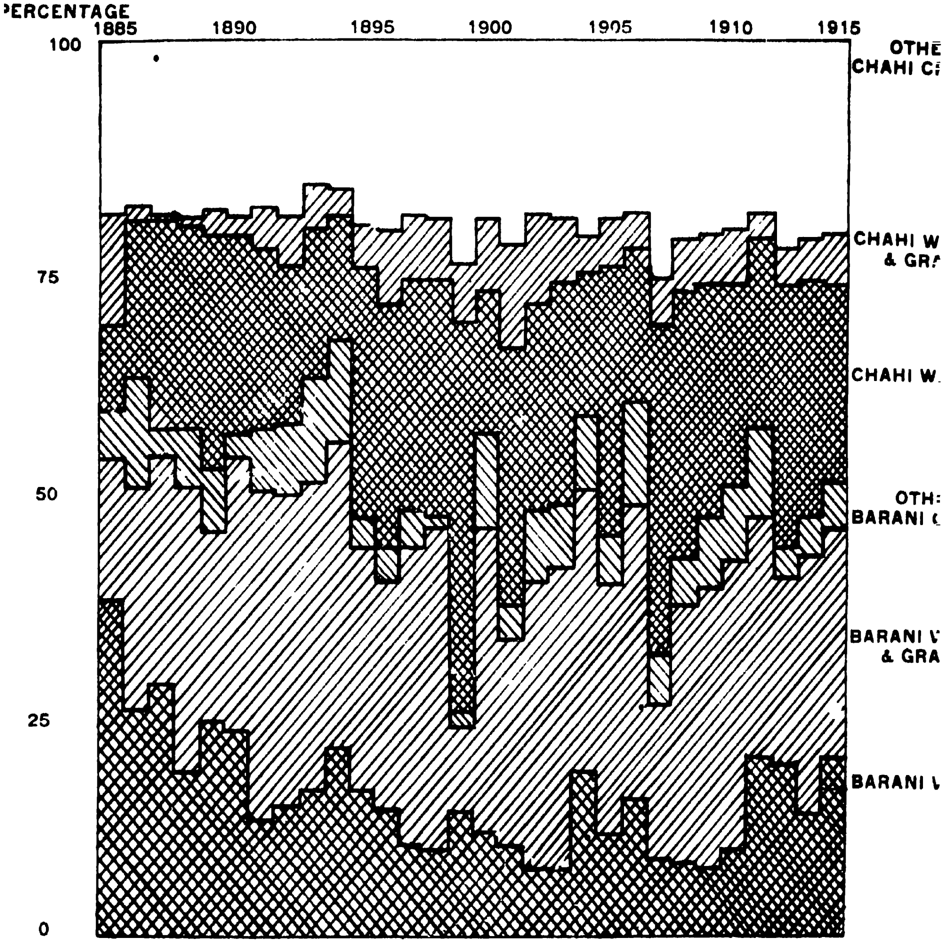


DIAGRAM VII.

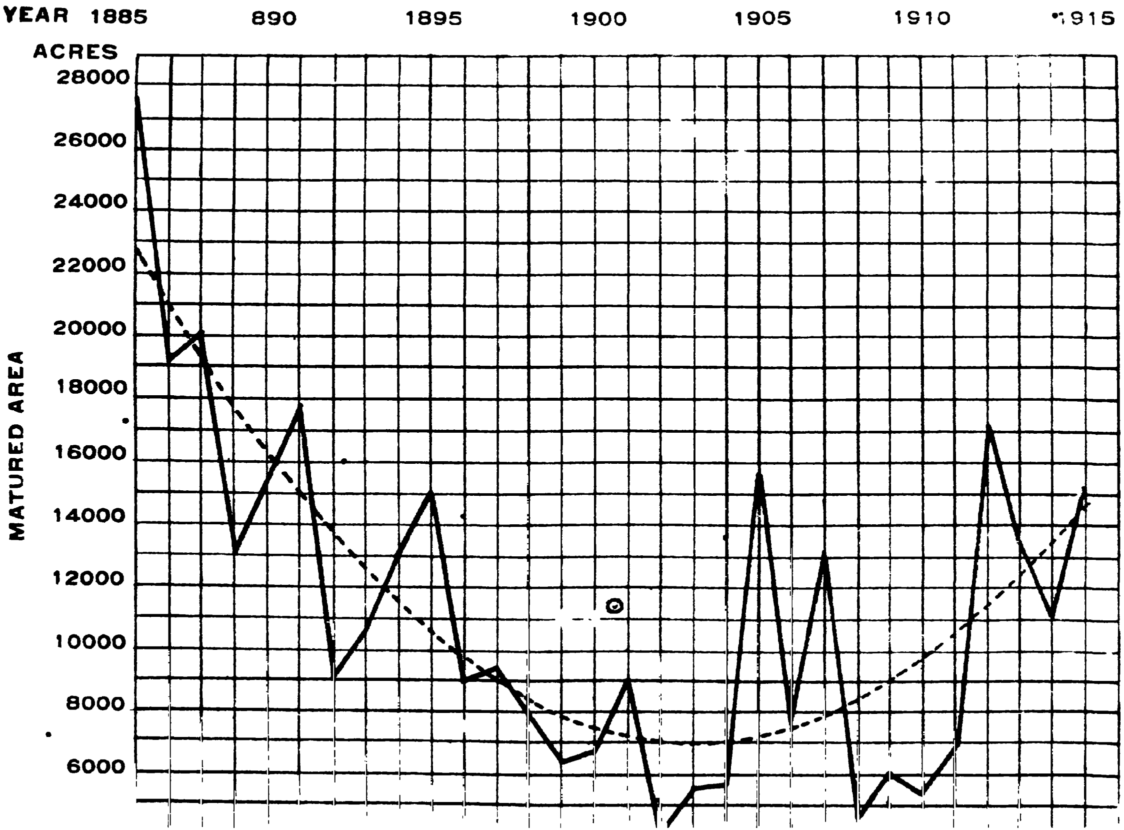
Dona Charhda. (RABI CROPS SOWN)

PERCENTAGE OF EACH KIND OF CROP.



DONA CHARHDA CI JULLUNDUR TAHSIL

UNIRRIGATED WHEAT



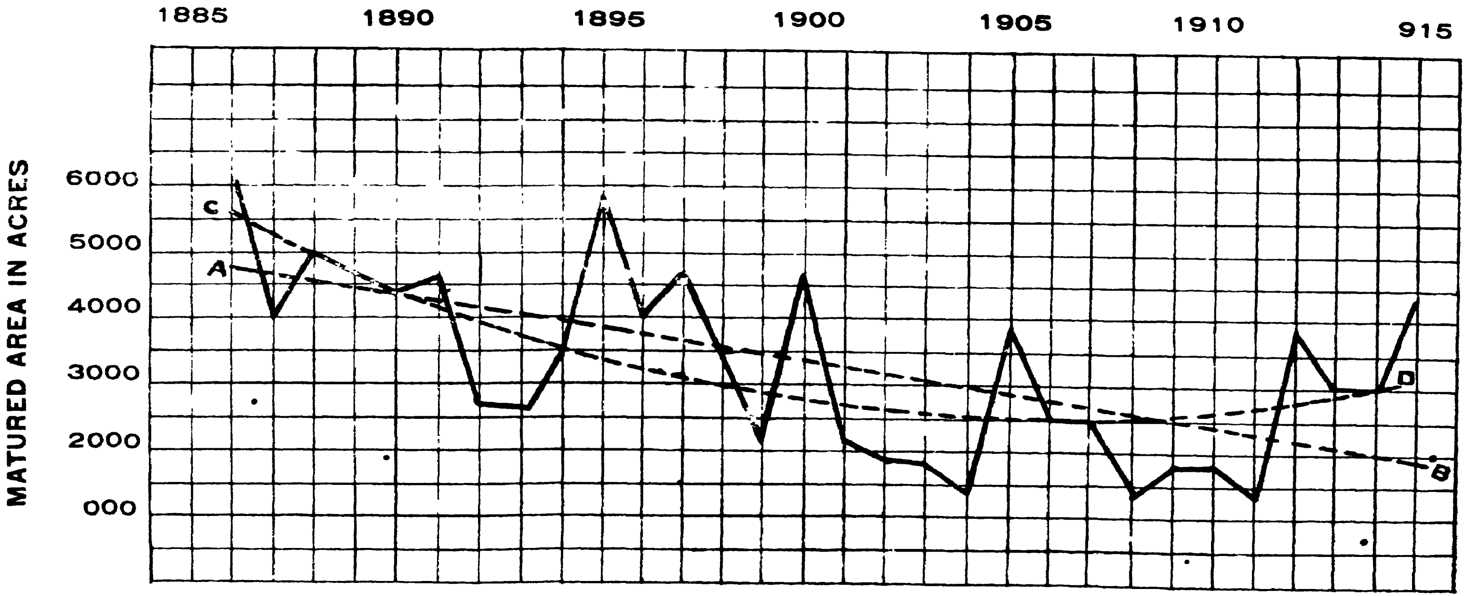
THE EQUATION OF THE PARABOLA OF CLOSEST FIT REFERRED TO THE CENTRE AS ORIGIN IS

$$Y = -2{\cdot}01 - 0{\cdot}27X + 0{\cdot}108X^2$$

DIAGRAM IX.

DONA LEHNDA CIRCLE JULLUNDUR TAHSIL

UNIRRIGATED WHEAT



AB IS THE STRAIGHT LINE OF CLOSEST FIT.
CD IS THE 2ND ORDER PARABOLA OF CLOSEST FIT.
THE EQUATION OF AB REFERRED TO CENTRE OF THE RANGE IS
$Y = -\cdot 20\ 2X$, AND OF CD. $Y = -\cdot 56 - \cdot 17X + \cdot 03X^2$.
THE LINE OF CLOSEST FIT IS EQUIVALENT TO A DECREA
OF 100 ACRES PER ANNUM.

DIAGRAM X.

SIRWAL BARANI WHEAT.

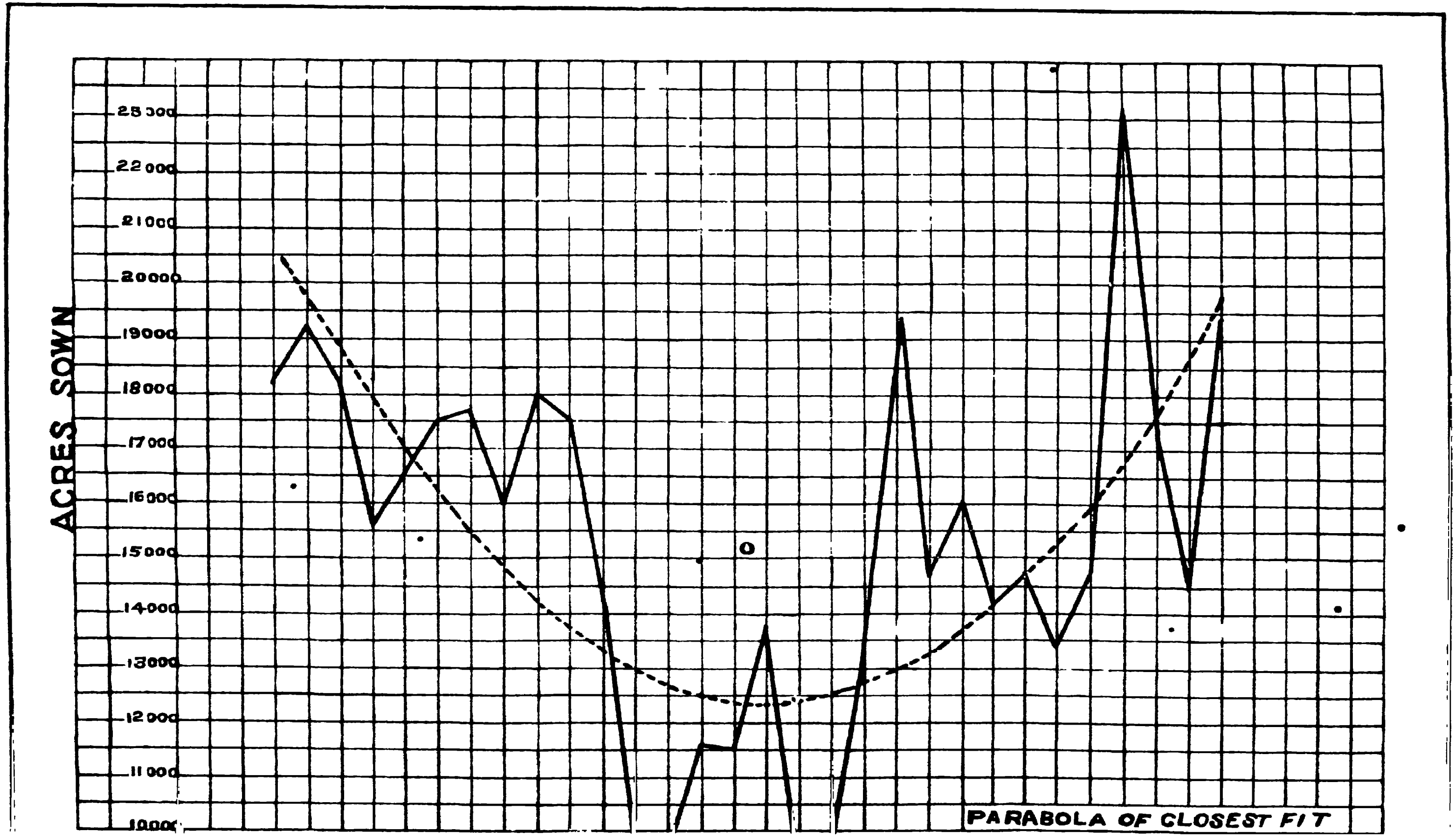
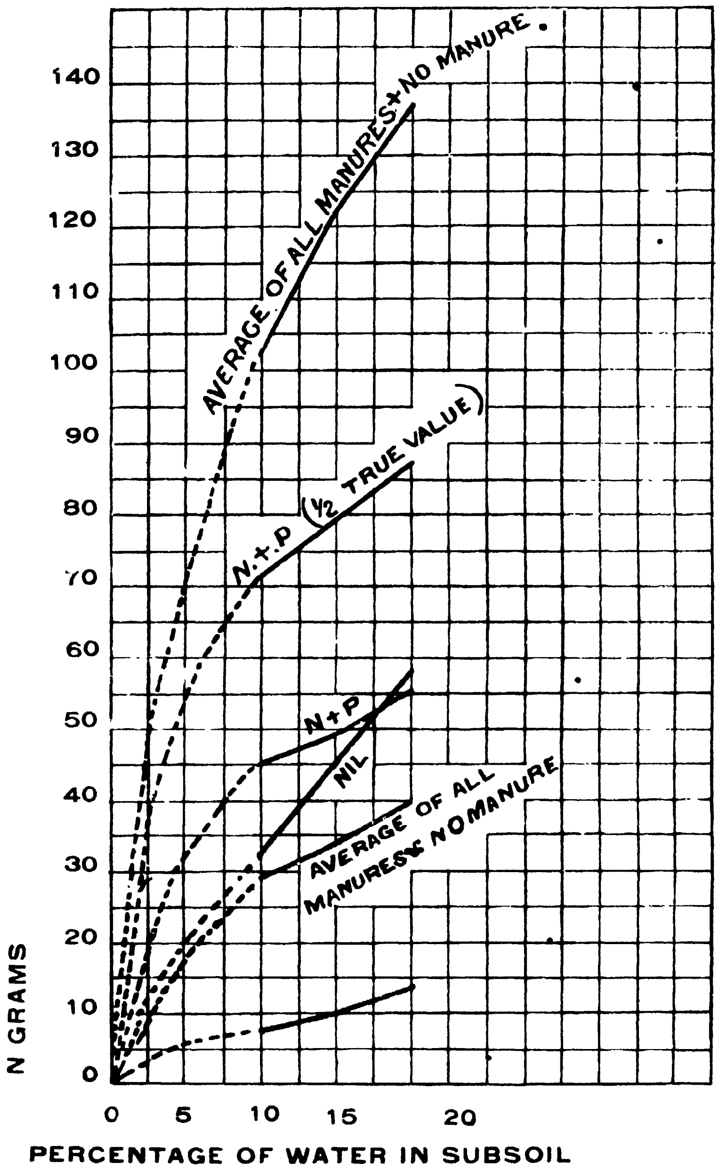


DIAGRAM XI.

EFFECT OF SOIL SATURATION ON YIELD OF WHEAT



N= CaCN2 P= SUPERPHOSPHATE
THE LOWER SOLID LINE IS THE AMOUNT OF SEED,
THE UPPER SOLID LINE IS THE TOTAL DRY CROP.
DOTTED LINES GIVE ASSUMED INTERPOLATIONS